Massive Stars as Drivers of the Galactic Ecosystem

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The most massive stars are also the most luminous

Basic properties of massive stars - O stars

recall, spectral type sequence: OBAFGKM

mass ~ 50 M_{sun}

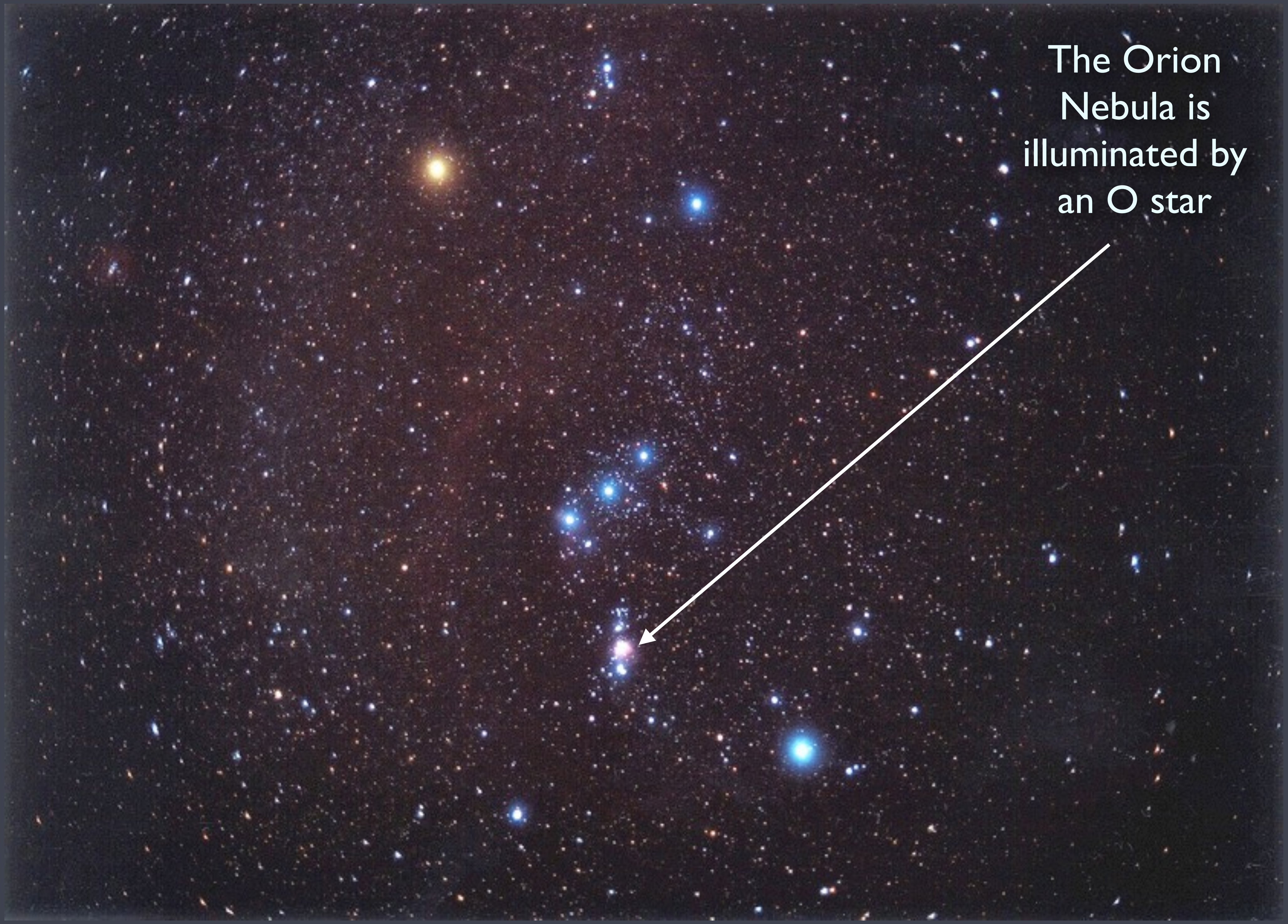
luminosity ~ 10^6 L_{sun} (Watts of radiated power)

surface temperature ~ 45,000 K ~ 8 T_{sun}

zeta Ori : the brightest O star in the sky

O stars are found in star formation regions

because their own lives are so short



Sun and full Moon - factor of a million (10^6) in brightness

These luminous, massive stars are cosmic beacons

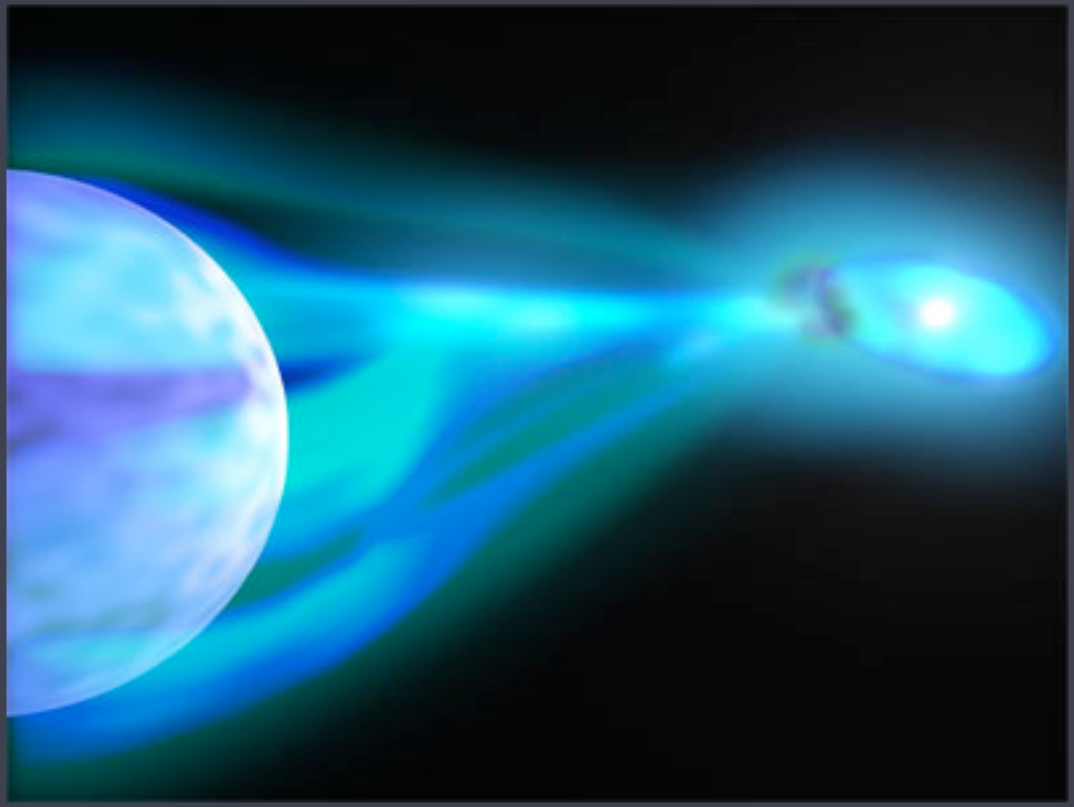
Whirlpool Galaxy, M51 (Hubble Space Telescope)

The Whirlpool in X-rays

Whirlpool Galaxy, M51 (Chandra X-ray Telescope)

X-ray binaries

giant star accretes mass onto a neutron star or black hole



artists' renderings

Tarantula Nebula in the LMC

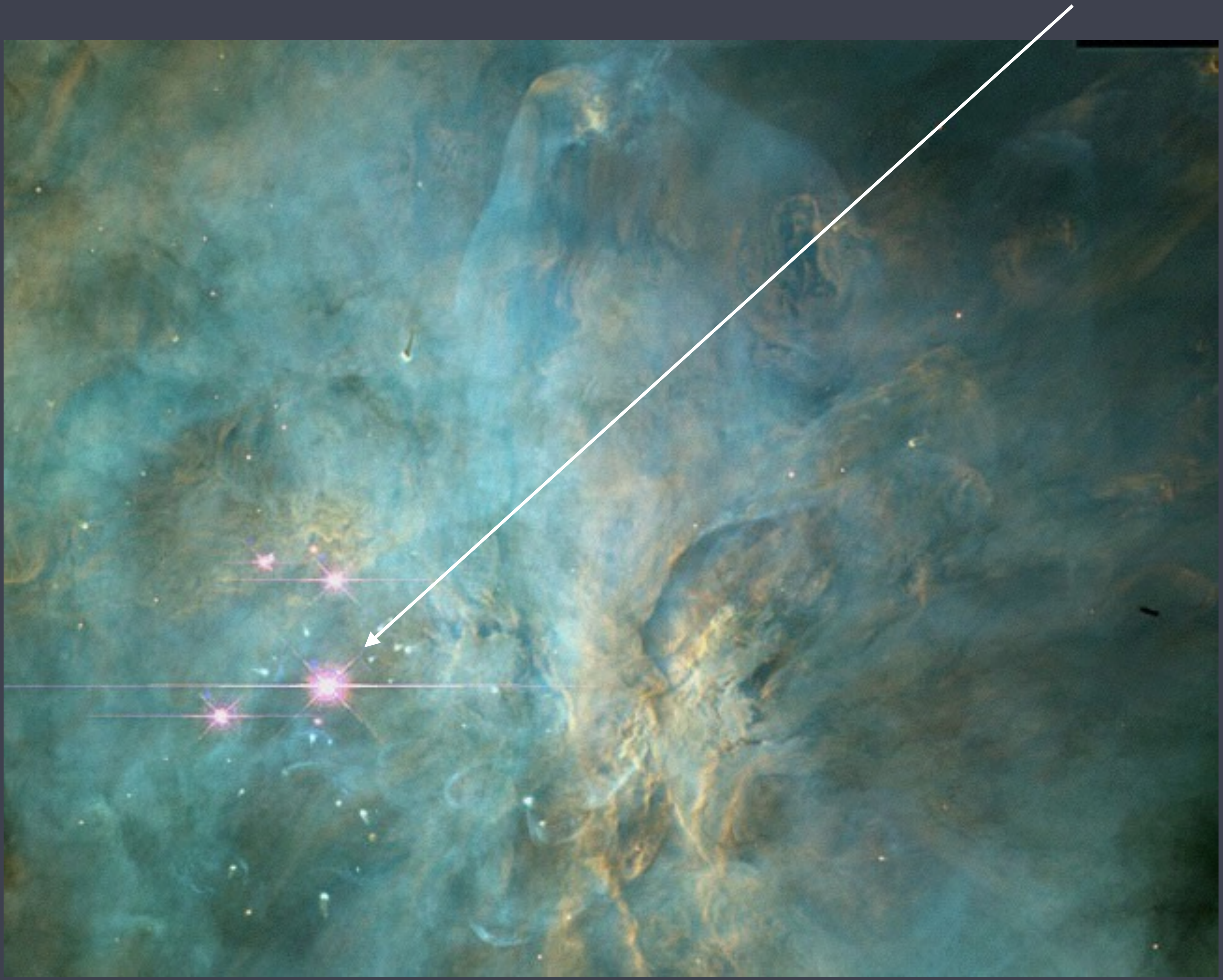
http://apod.nasa.gov/apod/ap160226.html - Tarantula Nebula (Hubble Space Telescope)

R136 in Tarantula

http://apod.nasa.gov/apod/ap160124.html - R136 (Hubble Space Telescope)

the Orion Nebula

theta-1 Ori C



The Orion Nebula in the Infrared

Orion Nebula and the Horsehead Nebula

Deep image of Orion: lots of gas and star formation

O Stars are characterized by their dense **stellar winds**

Prodigious matter, momentum, and kinetic energy input into the cluster environment via these winds

Carina (Hubble Space Telescope)

wind-blown bubble around a massive star

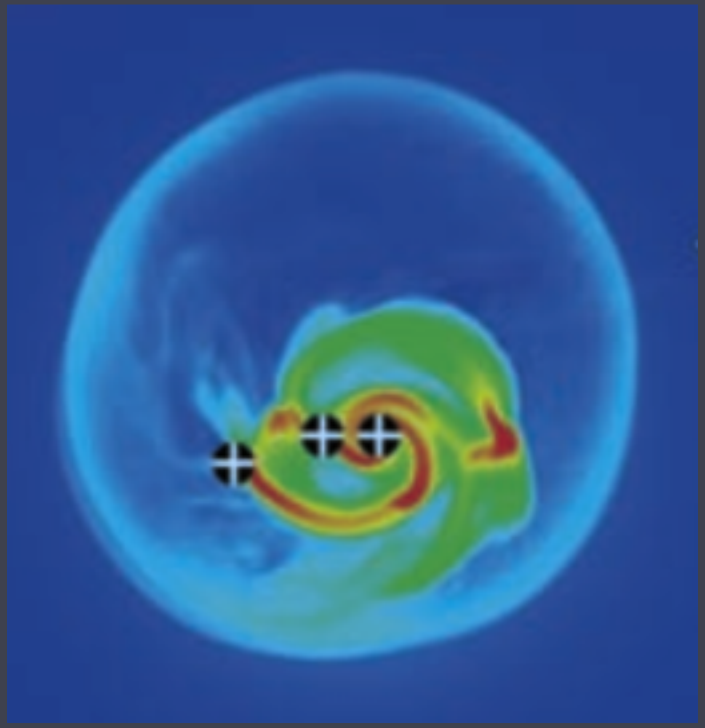
NGC 6888 Crescent Nebula - Tony Hallas

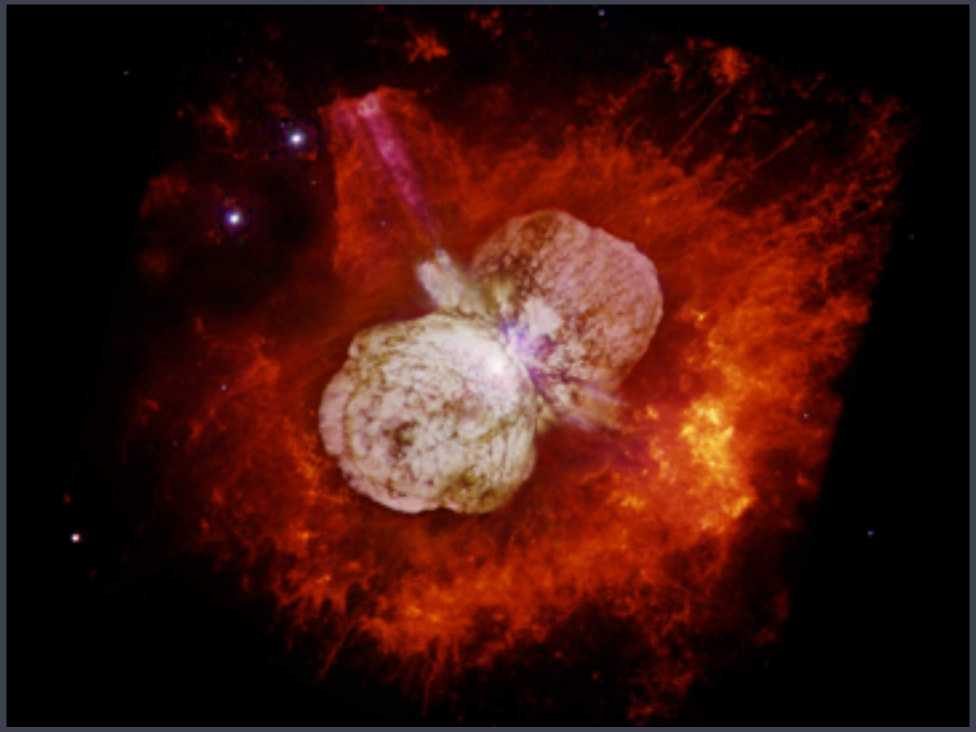
What drives these winds?

Radiation Force, the *momentum* in starlight

Massive stars' lives

formation, evolution, death

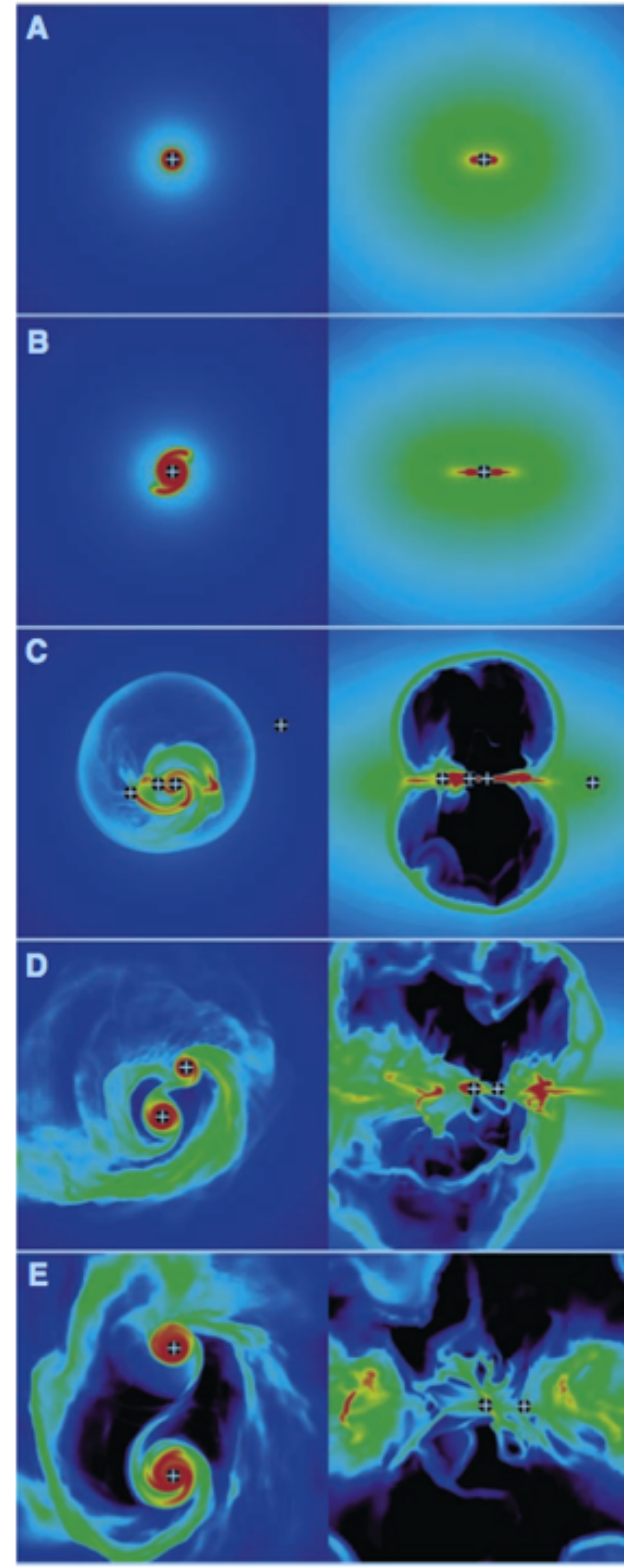




Star formation simulation

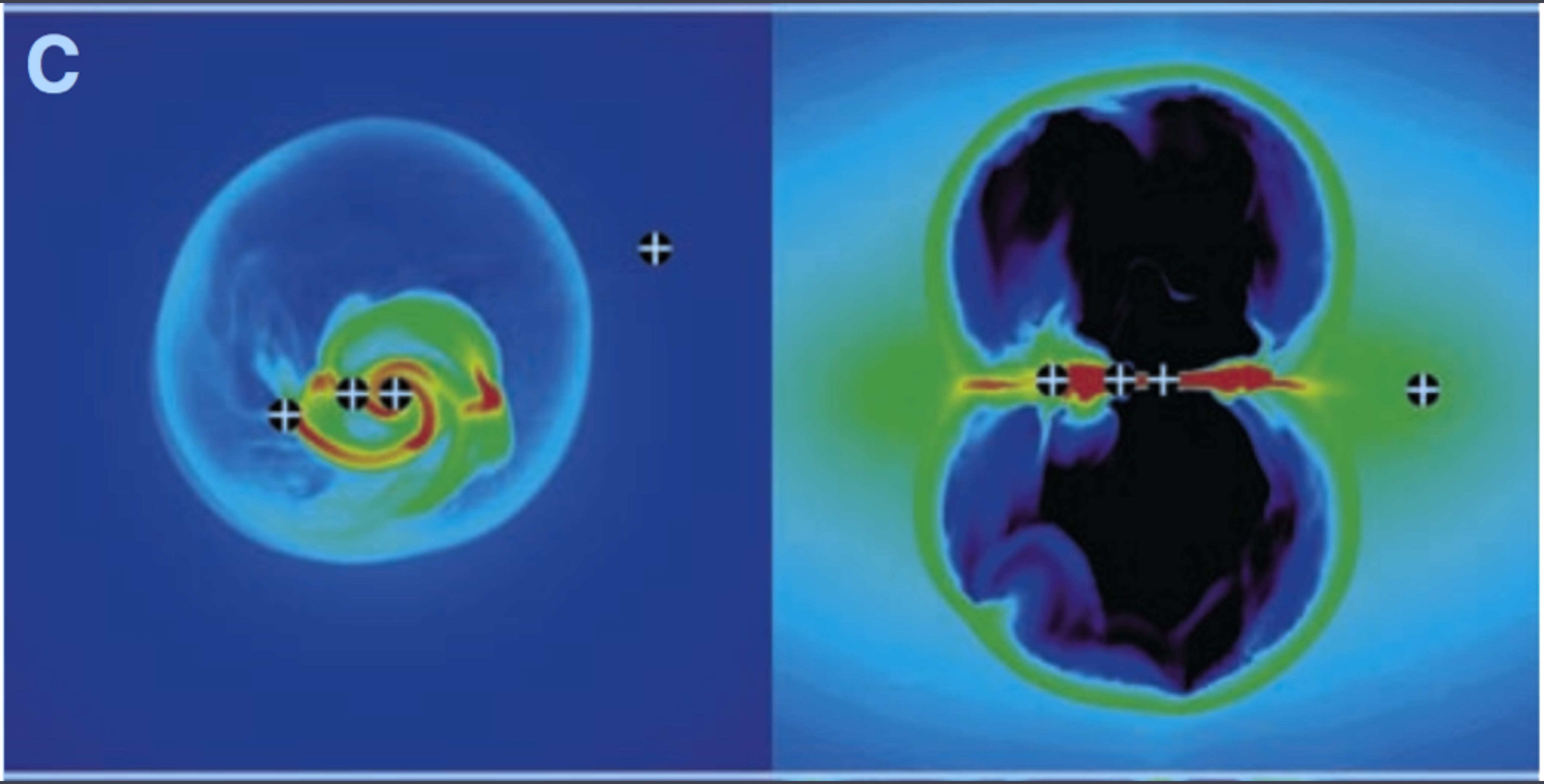
M. Krumholz (Science, 2009)

Fig. 1. Snapshots of the simulation at (**A**) 17,500 years, (**B**) 25,000 years, (**C**) 34,000 years, (**D**) 41,700 years, and (**E**) 55,900 years. In each panel, the left image shows column density perpendicular to the rotation axis in a $(3000\ \text{AU})^2$ region; the right image shows volume density in a $(3000\ \text{AU})^2$ slice along the rotation axis. The color scales are logarithmic (black at the minimum, red at the maximum), from 10^0 to $10^{2.5}$ g cm^{-2} on the left and 10^{-18} to 10^{-14} g cm^{-3} on the right. Plus signs indicate the projected positions of stars. See figs. S1 to S3 and movie S1 for additional images.



Massive star formation is difficult

The energy generated by accretion pushes away the accreting gas



gas velocity (left) and net forces (right)

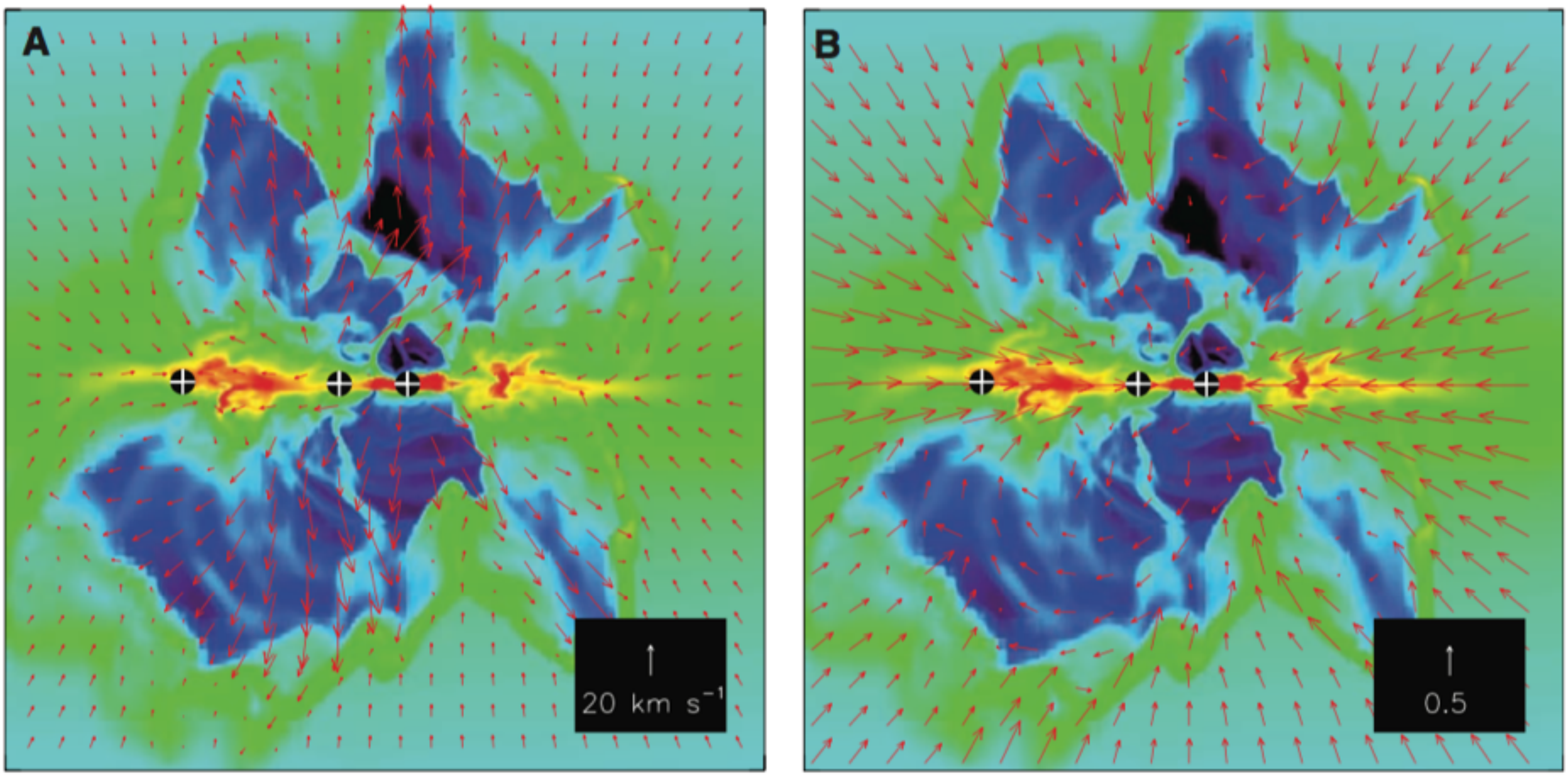
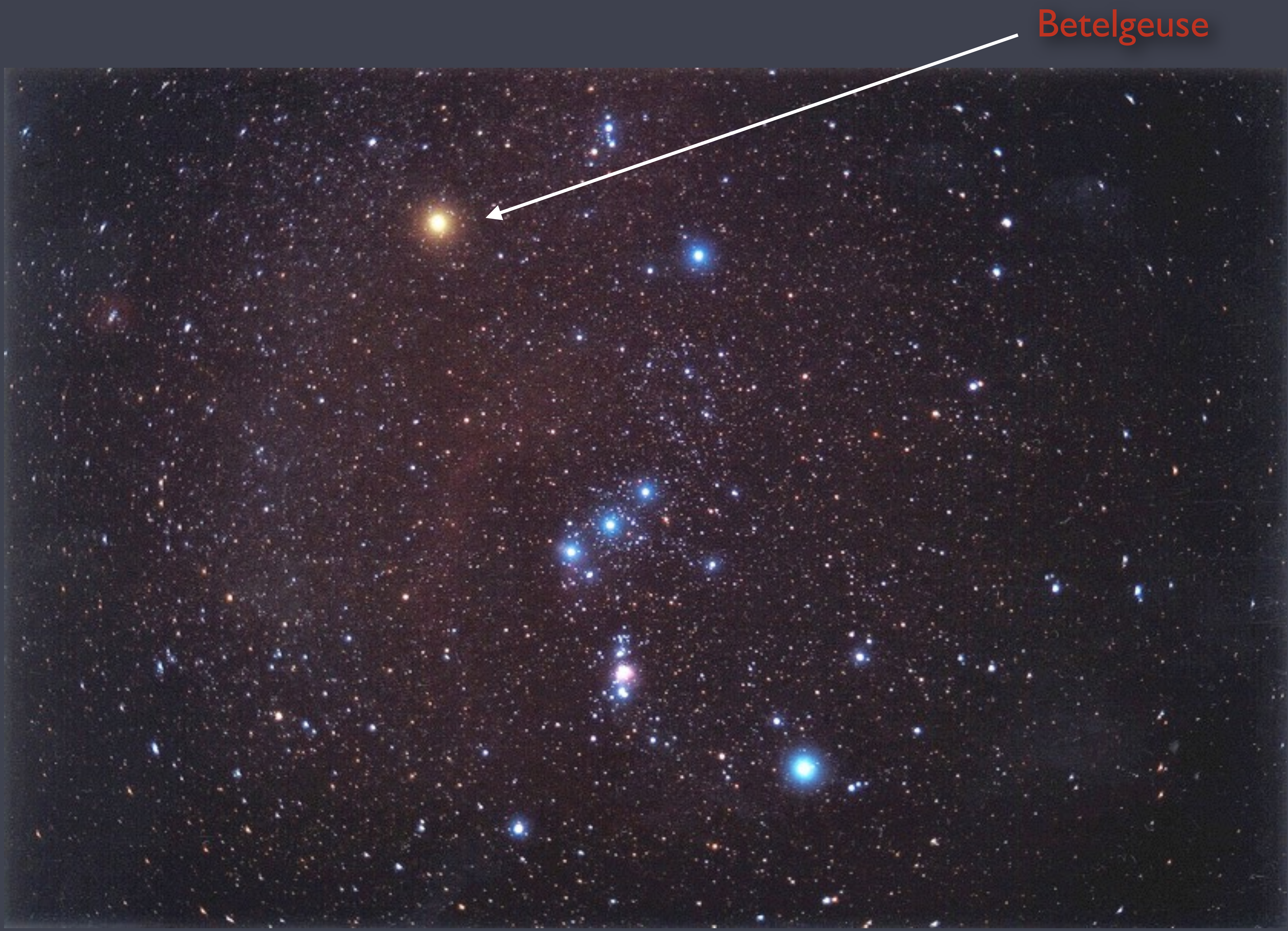


Fig. 3. Snapshot of a (6000 AU)^2 slice along the rotation axis at 51,100 years. Color indicates density from 10^{-20} to 10^{-14} g cm^{-3} on a logarithmic scale as in Fig. 1. Plus signs show projected stellar positions. **(A)** Arrows show gas velocity. **(B)** Arrow directions indicate the direction of the net (radiation plus gravitational) force; lengths are proportional to the magnitude of the net force divided by the magnitude of the gravitational force. Thus, an inward arrow of length 1 represents negligible radiation force.

M. Krumholz (Science, 2009)

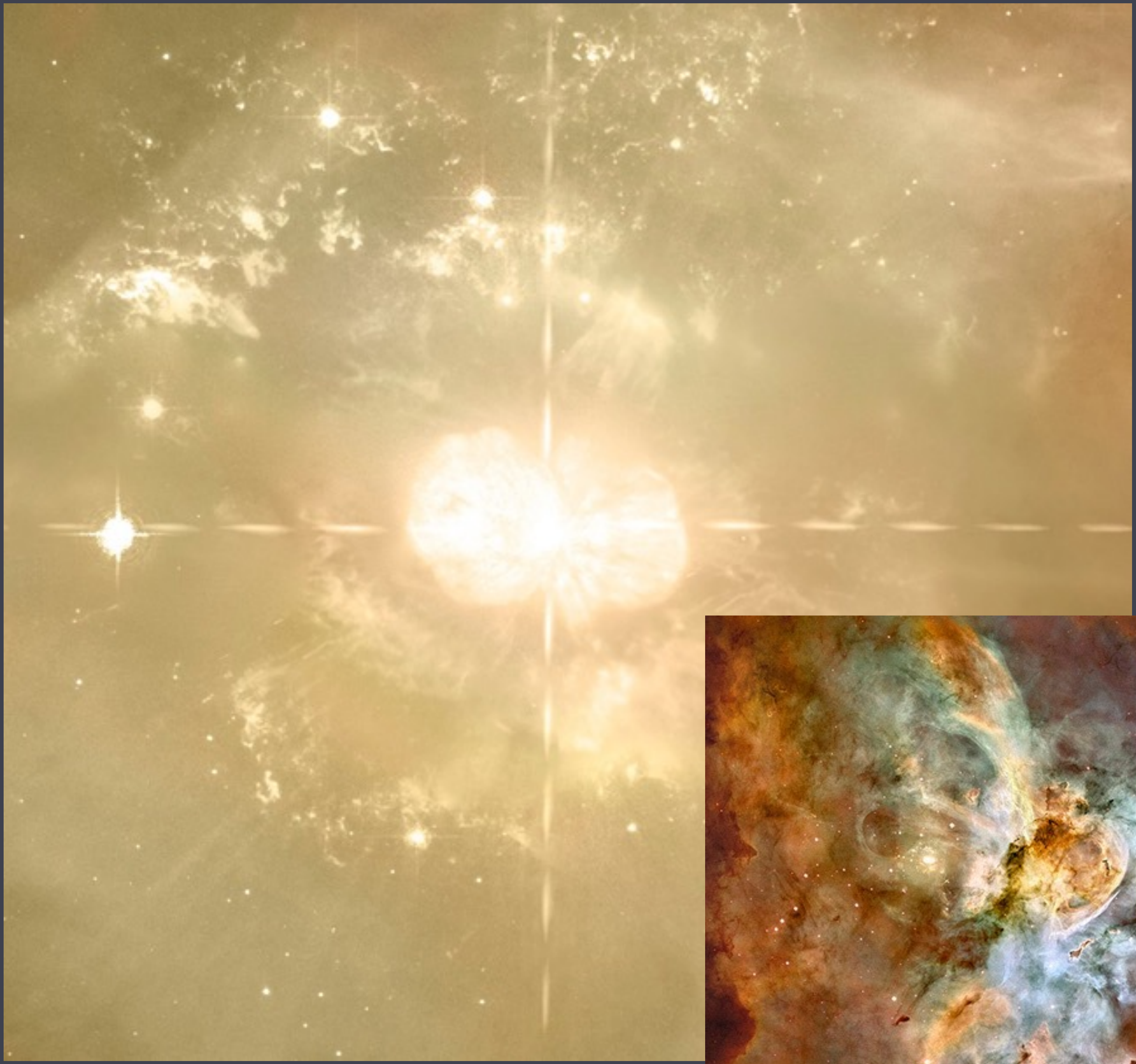
Life/evolution of a massive star

Blue stars in middle age becomes red supergiants in old age



Life/evolution of a massive star

then they lose more mass, and become blue again

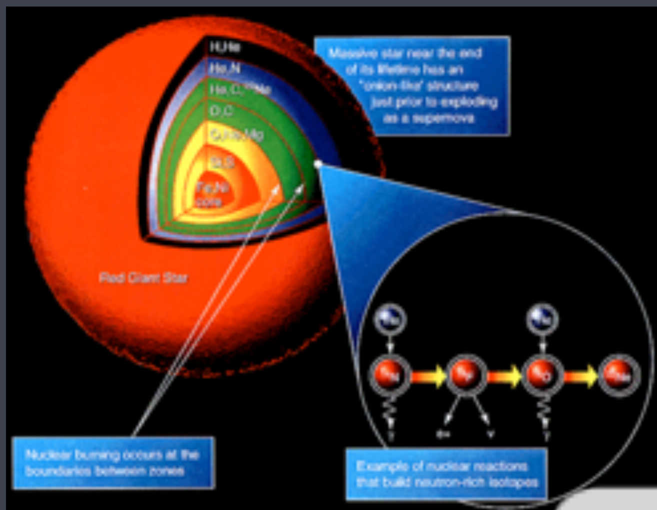


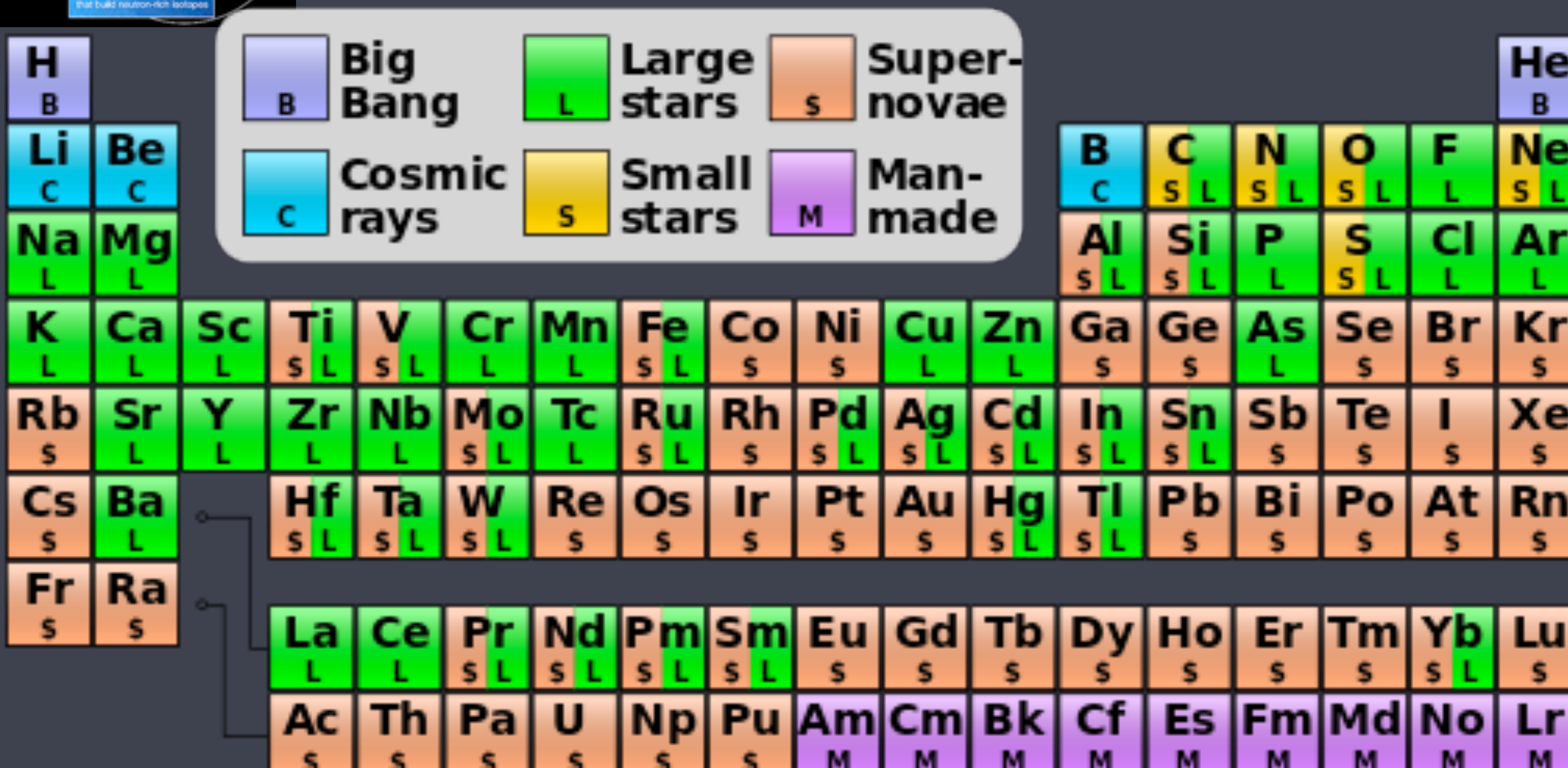
eta Carina

http://apod.nasa.gov/apod/ap080617.html - eta Carina (Hubble Space Telescope)

Life/evolution of a massive star

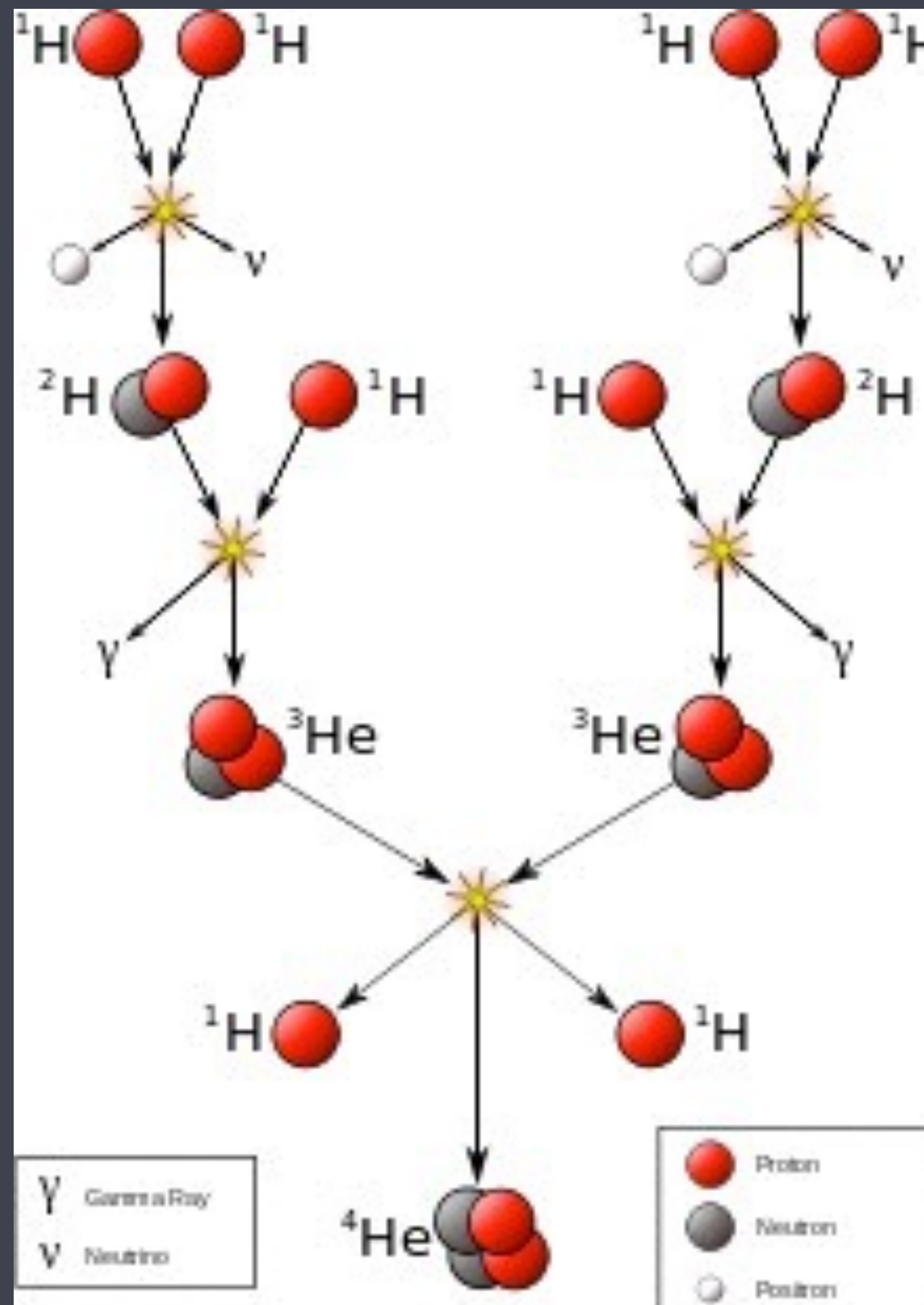
nucleosynthesis



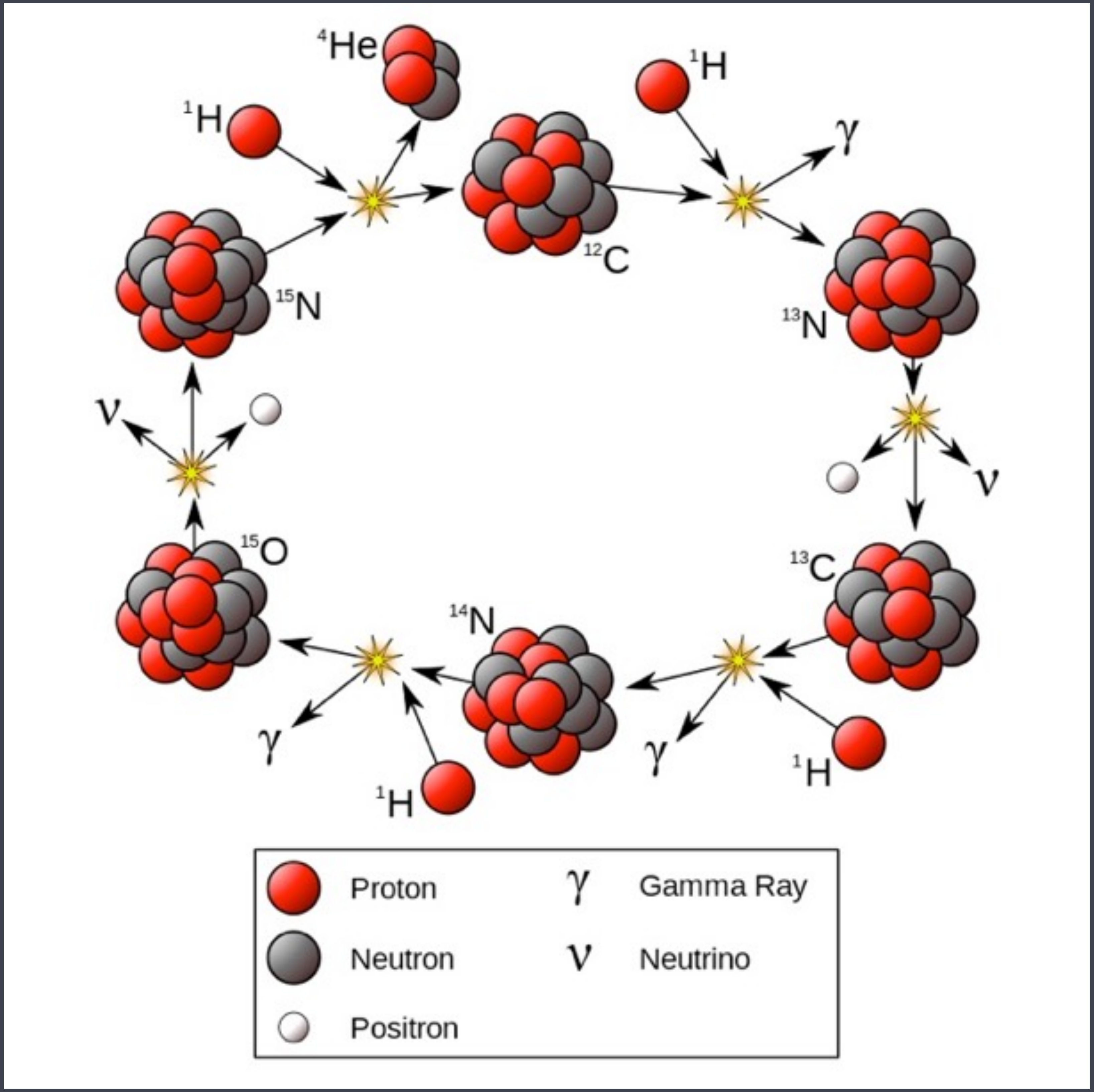


H to He fusion in low mass stars

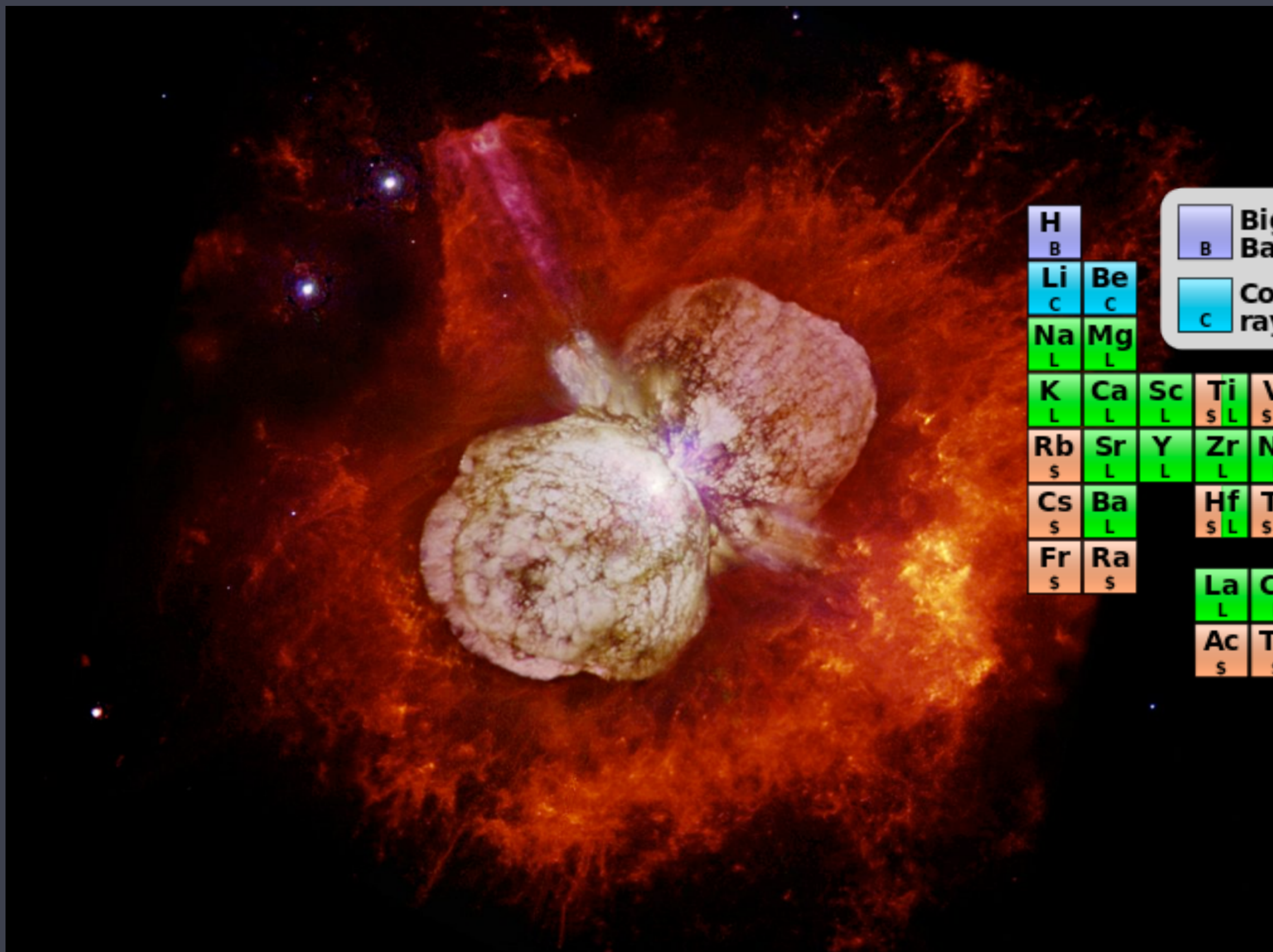
via the proton-proton chain

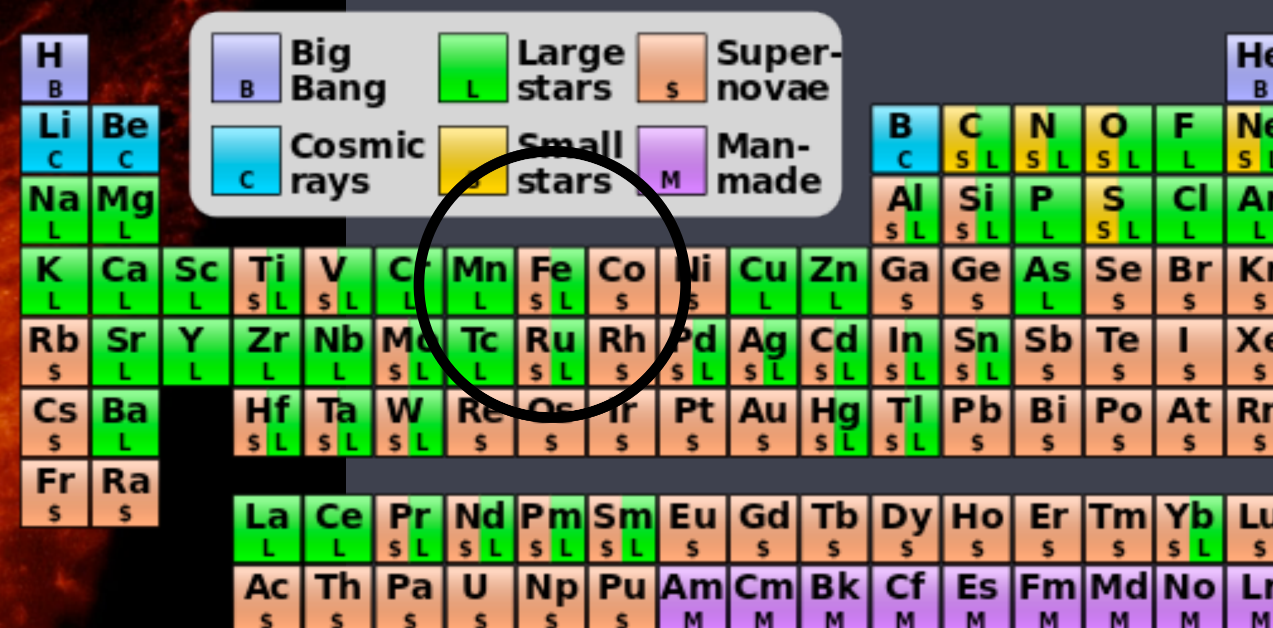


Massive stars fuse H to He via the CNO cycle

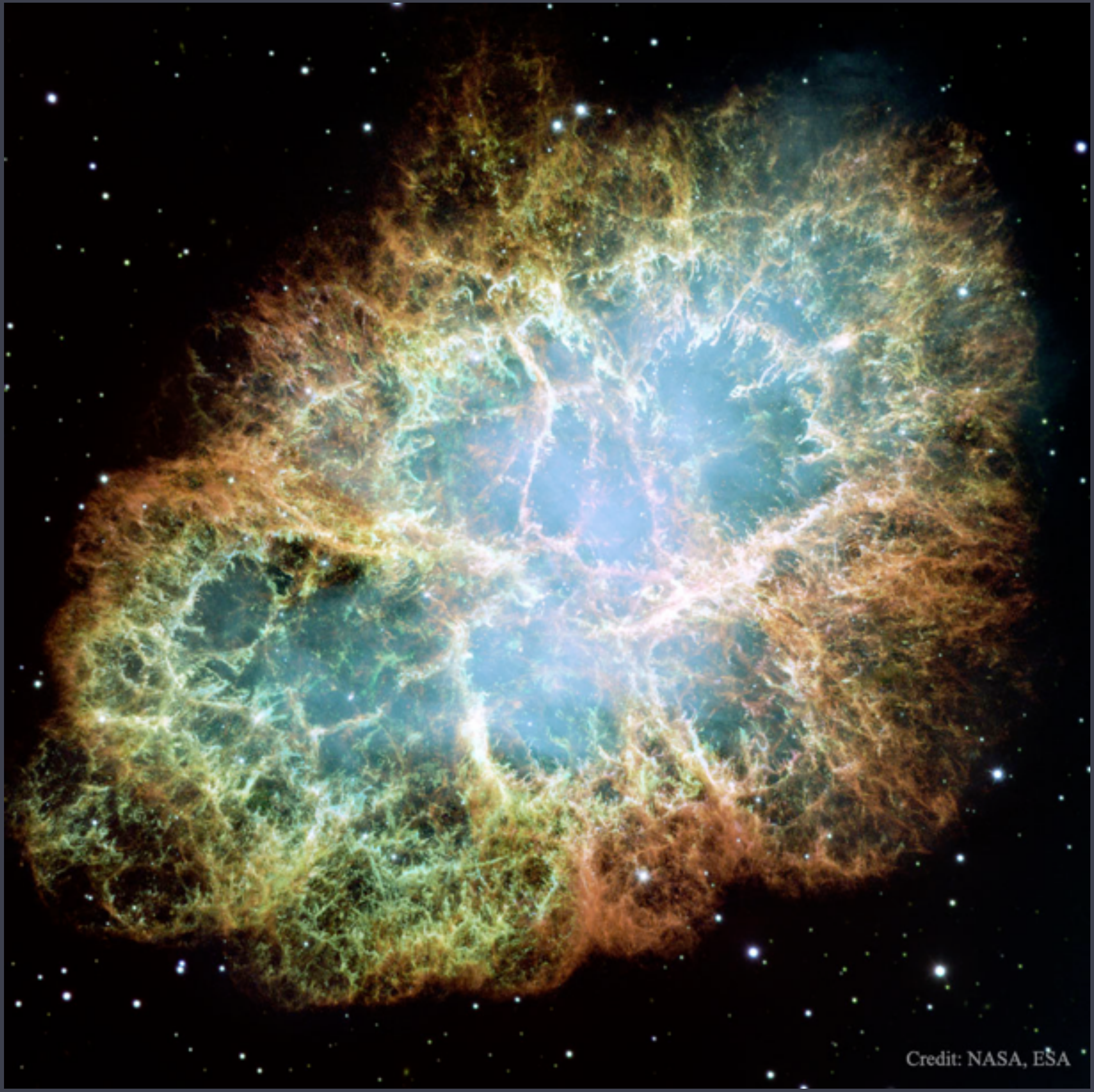


massive stars fuse elements all the way up to **iron**





Death of a massive star



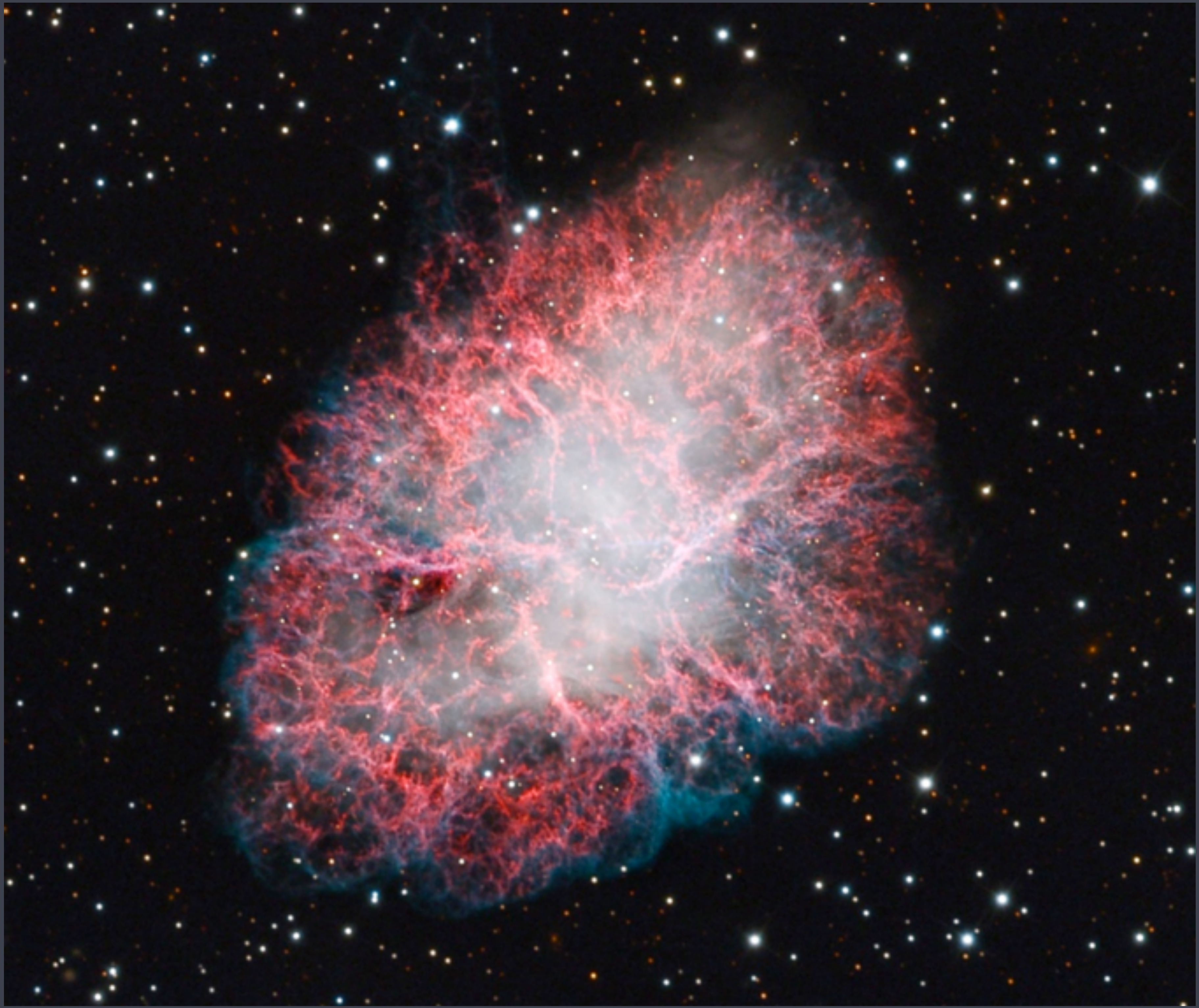
http://apod.nasa.gov/apod/ap150816.html - Crab Nebula (Hubble Space Telescope)

The expanding Crab

http://apod.nasa.gov/apod/ap011227.html - Crab Nebula (A. Block, NOAO)

The expanding Crab

https://vimeo.com/71117055

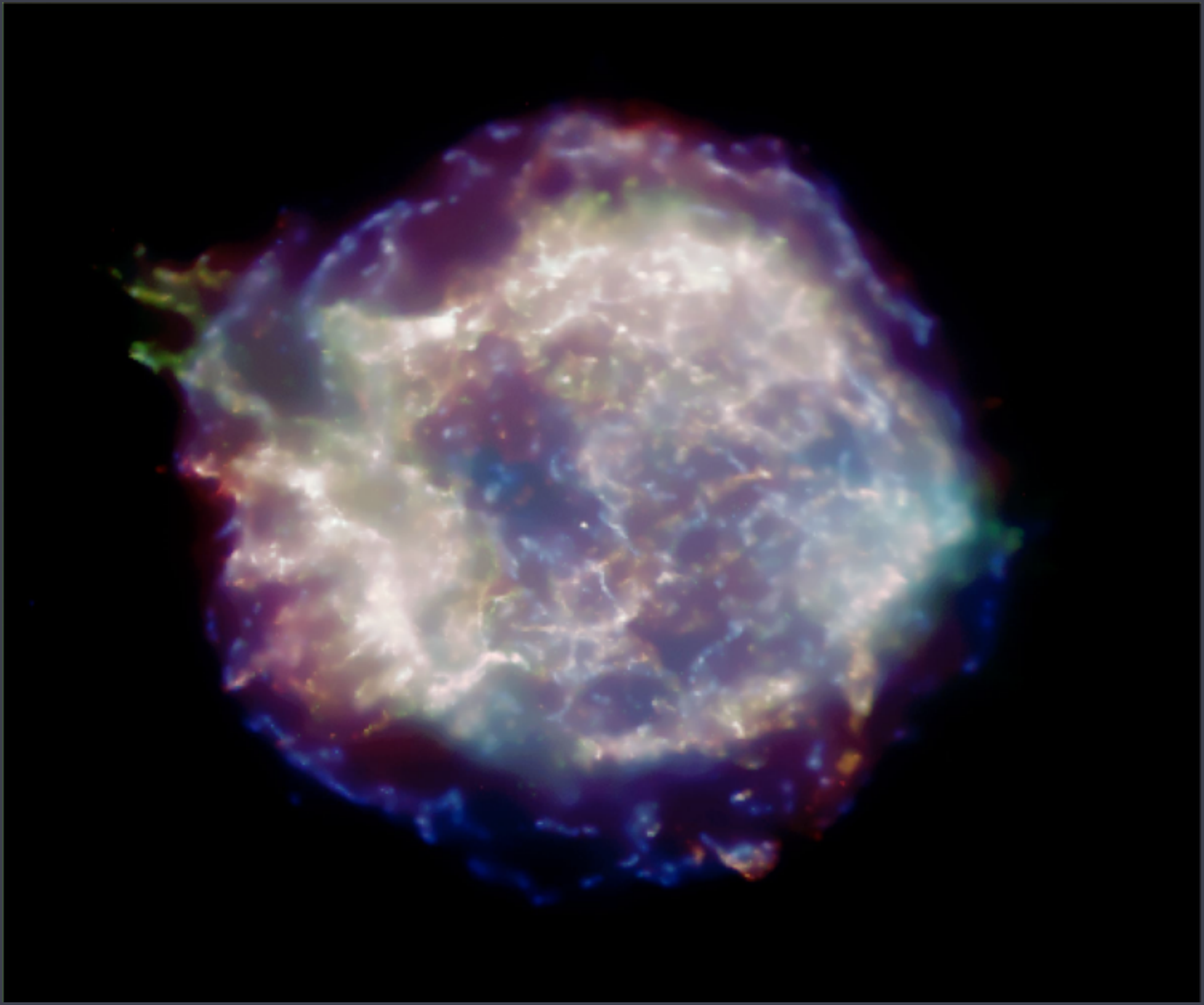


http://apod.nasa.gov/apod/ap130905.html - Crab Nebula (A. Block, Mt. Lemmon)

The remnant is a pulsar

http://apod.nasa.gov/apod/ap030904.html - Crab Pulsar (J. Hester, Chandra X-ray Telescope; Hubble Space Telescope)

Cas A



http://apod.nasa.gov/apod/ap020824.html - Cas A (J. Hughes, Chandra X-ray Telescope)

Vela Supernova Remnant (11,000 years old)

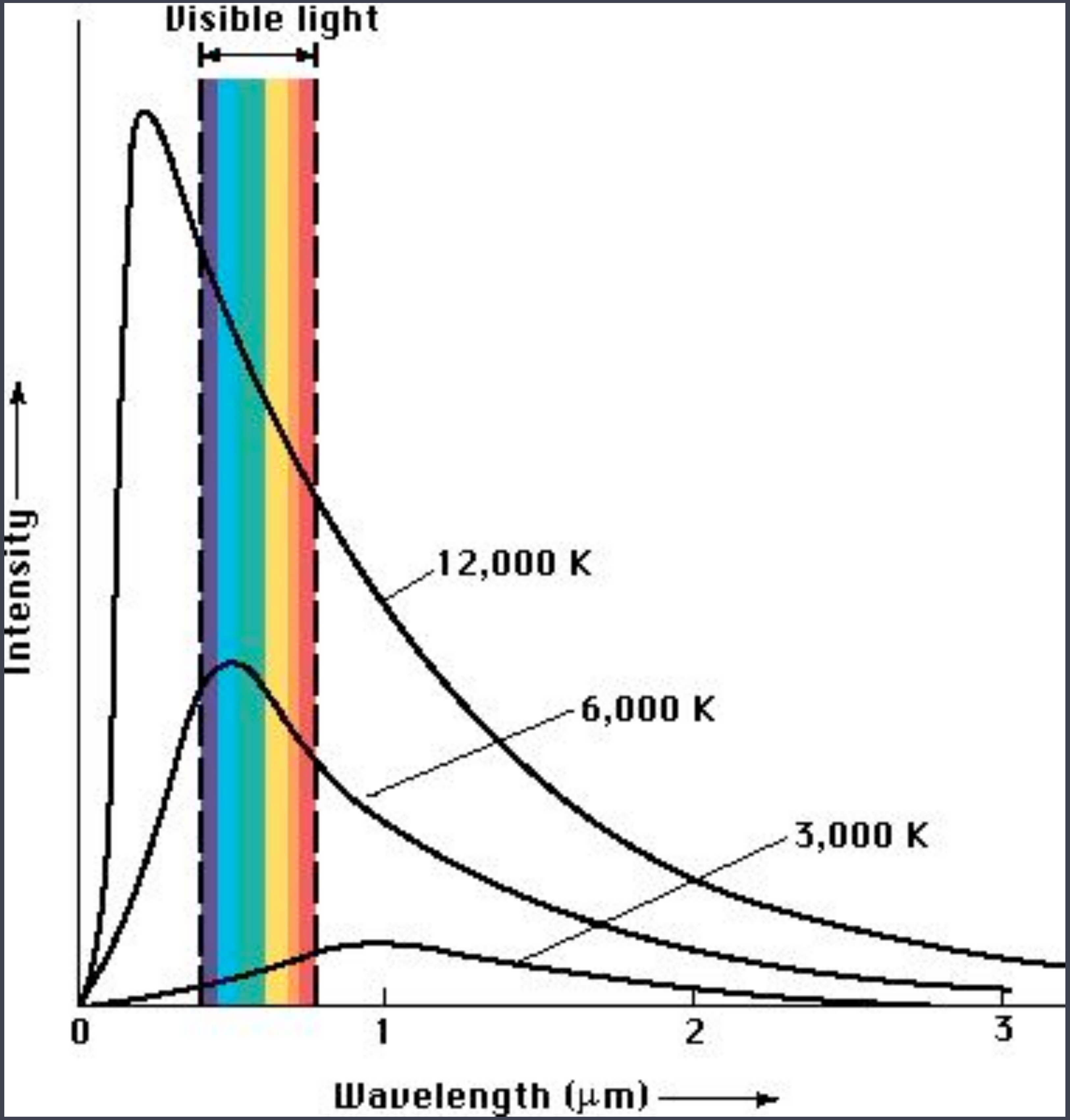
http://apod.nasa.gov/apod/ap150101.html - Vela (W. Leitner, CEDIC)

This gas fades into the interstellar medium…

…enriched with heavy elements and ready to form a new generation of stars

X-ray studies of Massive Stars

Star's surface emission is basically blackbody



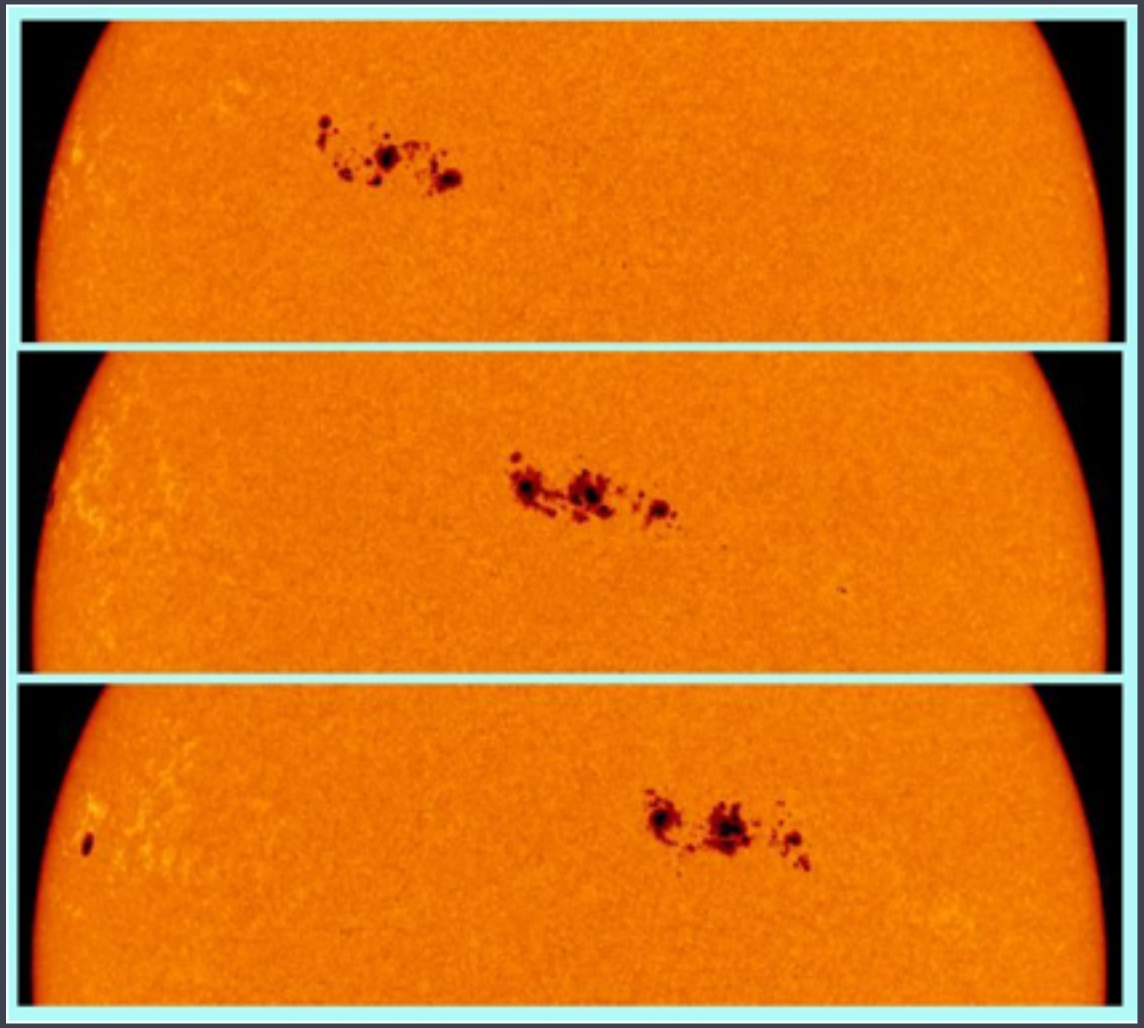
above T ~ 10,000 K most of a star's emission is in the UV

O stars are even more extreme: T > 30,000 K

even so, **no X-ray** emission from the photospheres (surfaces) of even the hottest stars

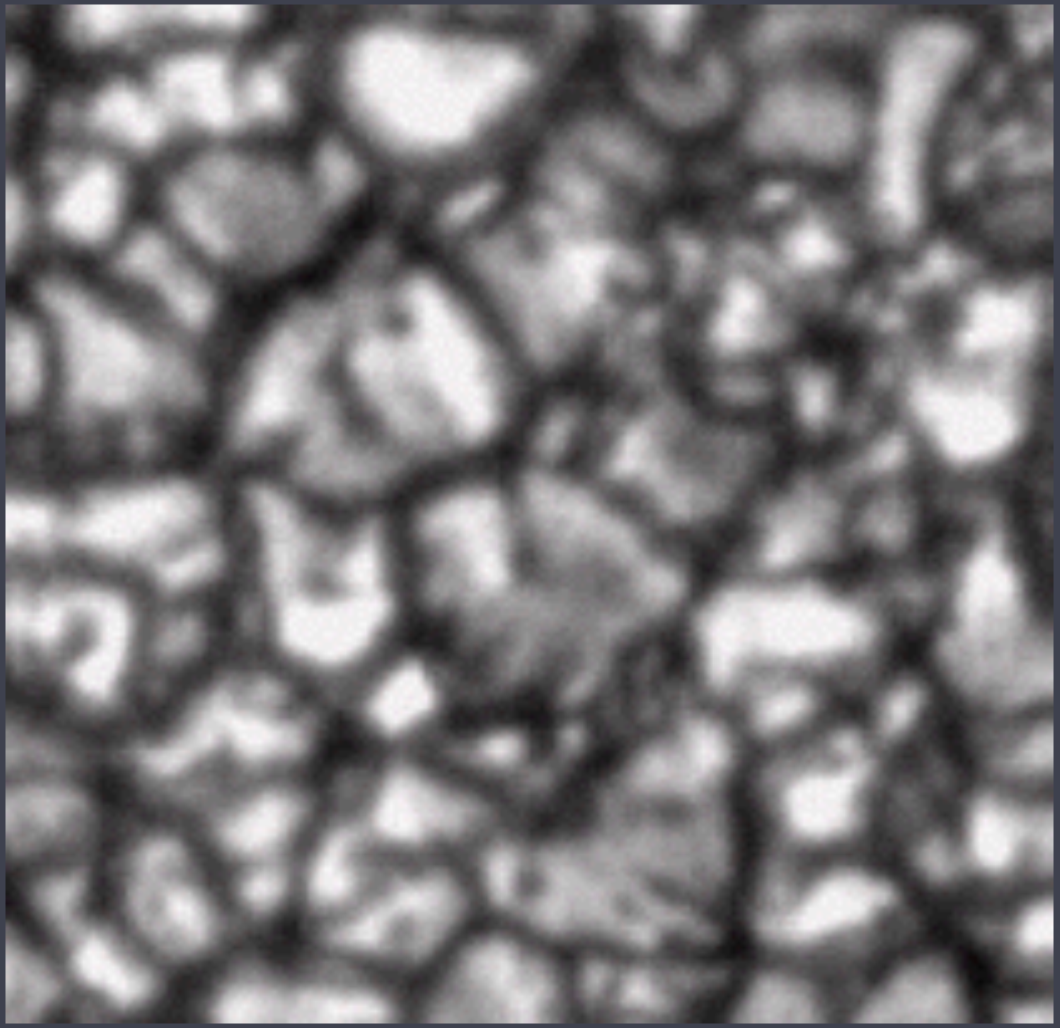
The Sun's **X-ray emission** is associated with its magnetic dynamo (rotation + convection are key ingredients)

rotation



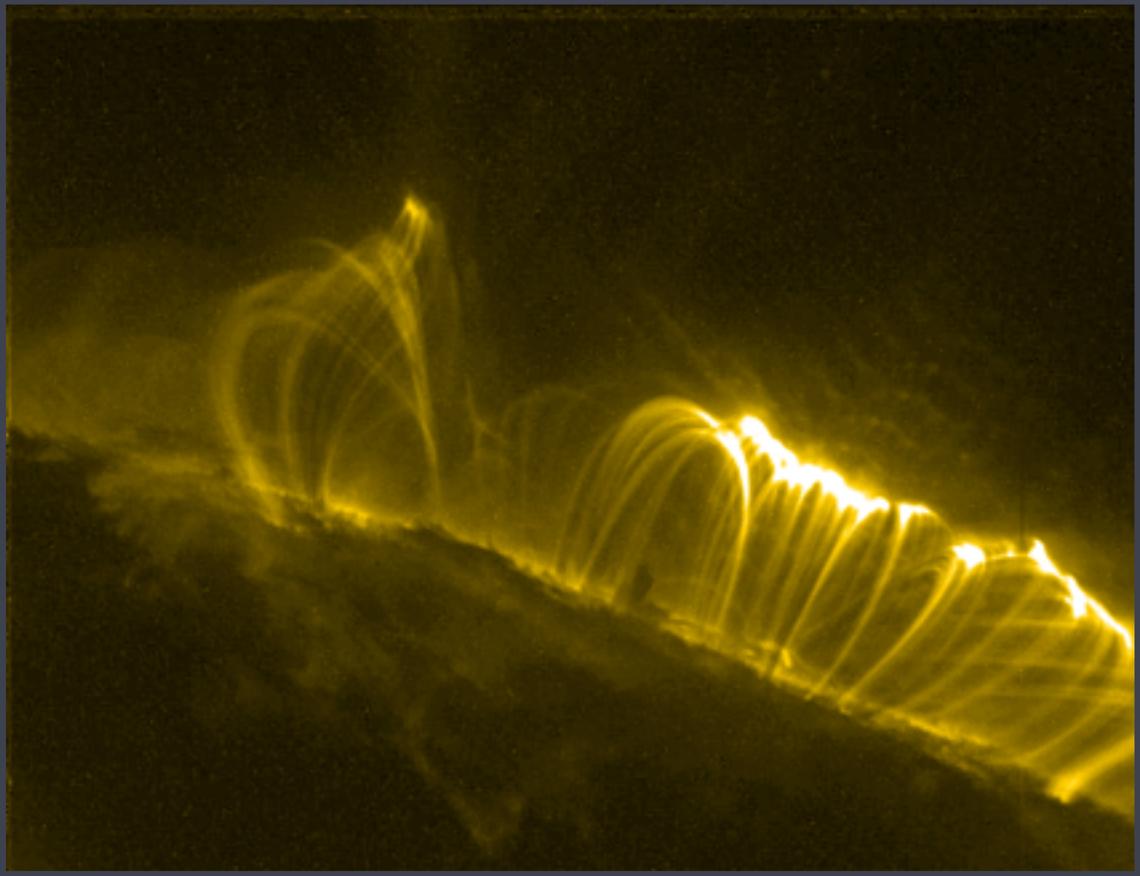
sunspots rotate across our field of view in a few days

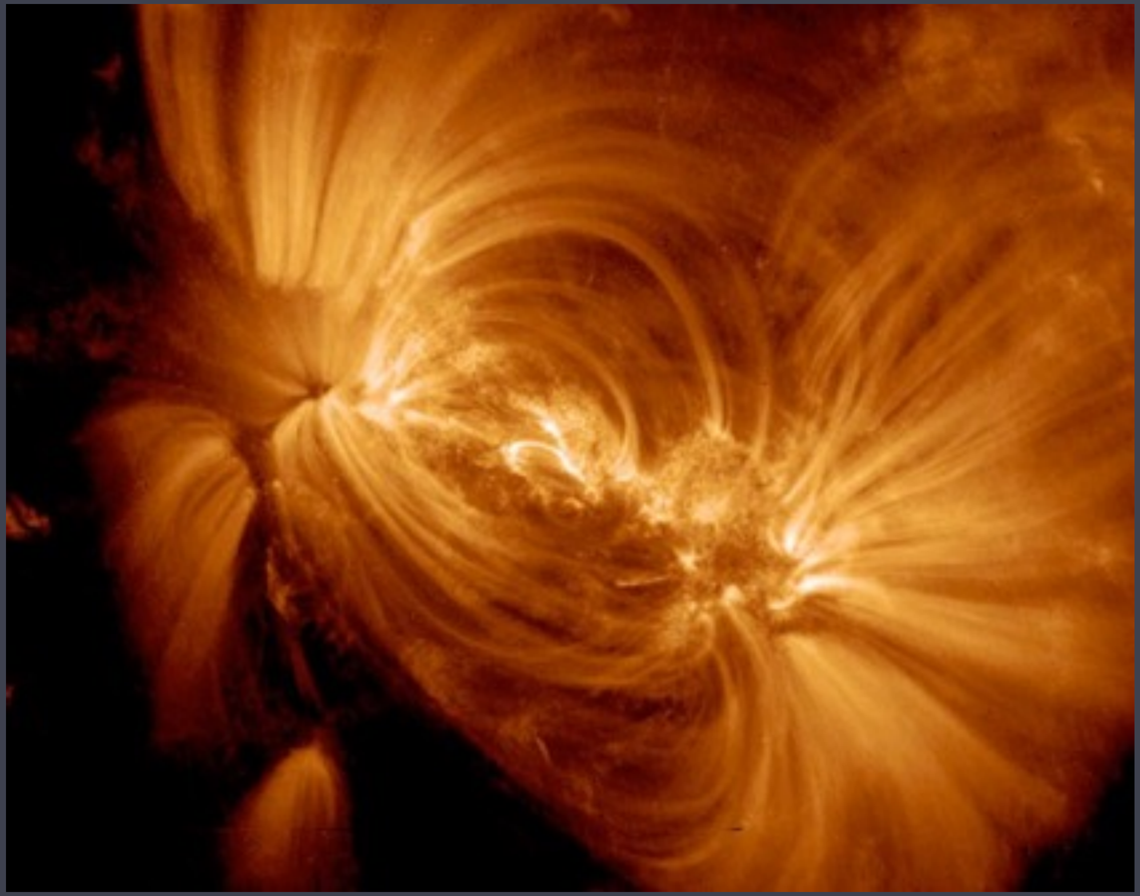
convection

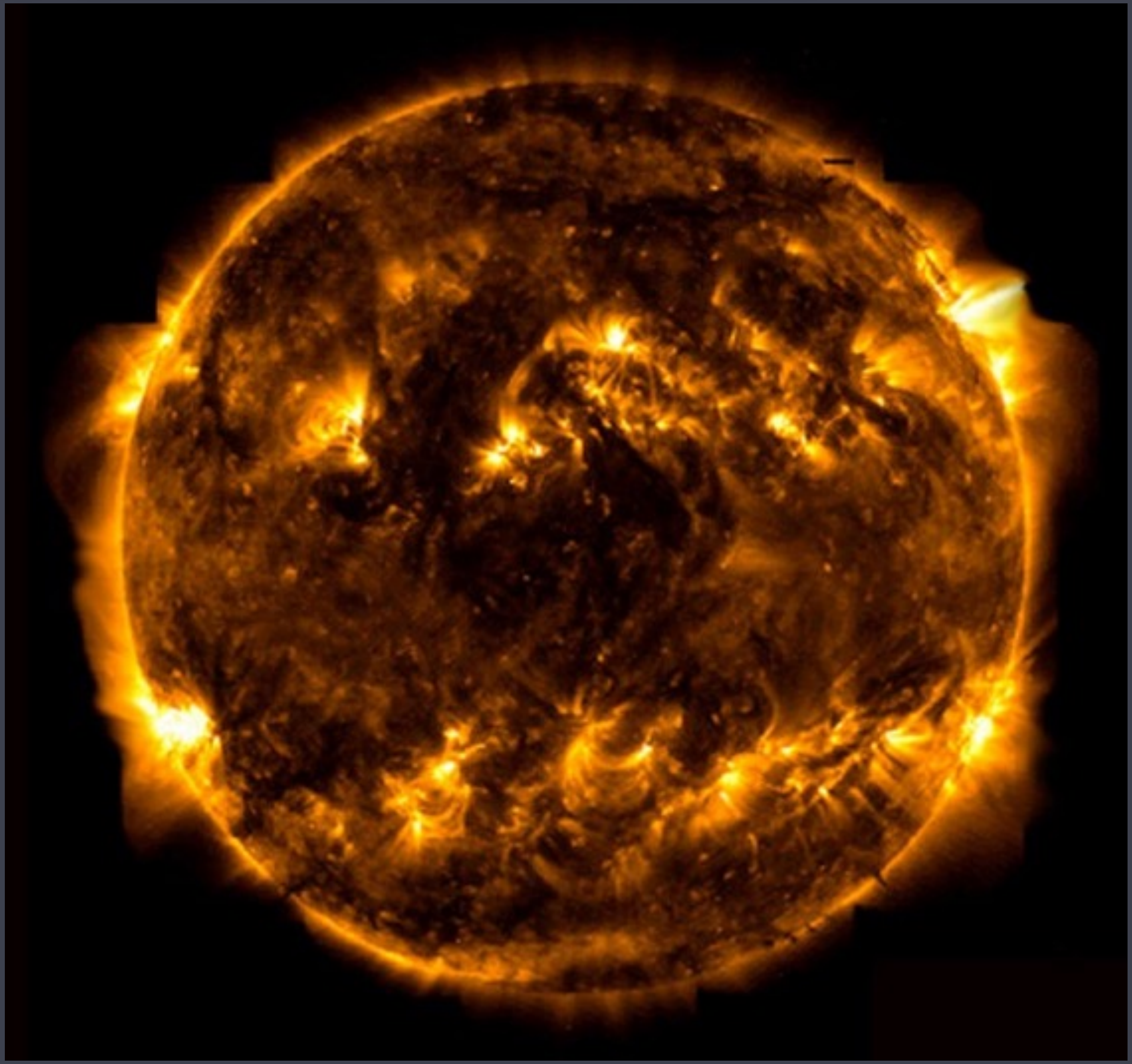


area roughly the size of the Earth

The Sun in the extreme ultraviolet







NASA: TRACE

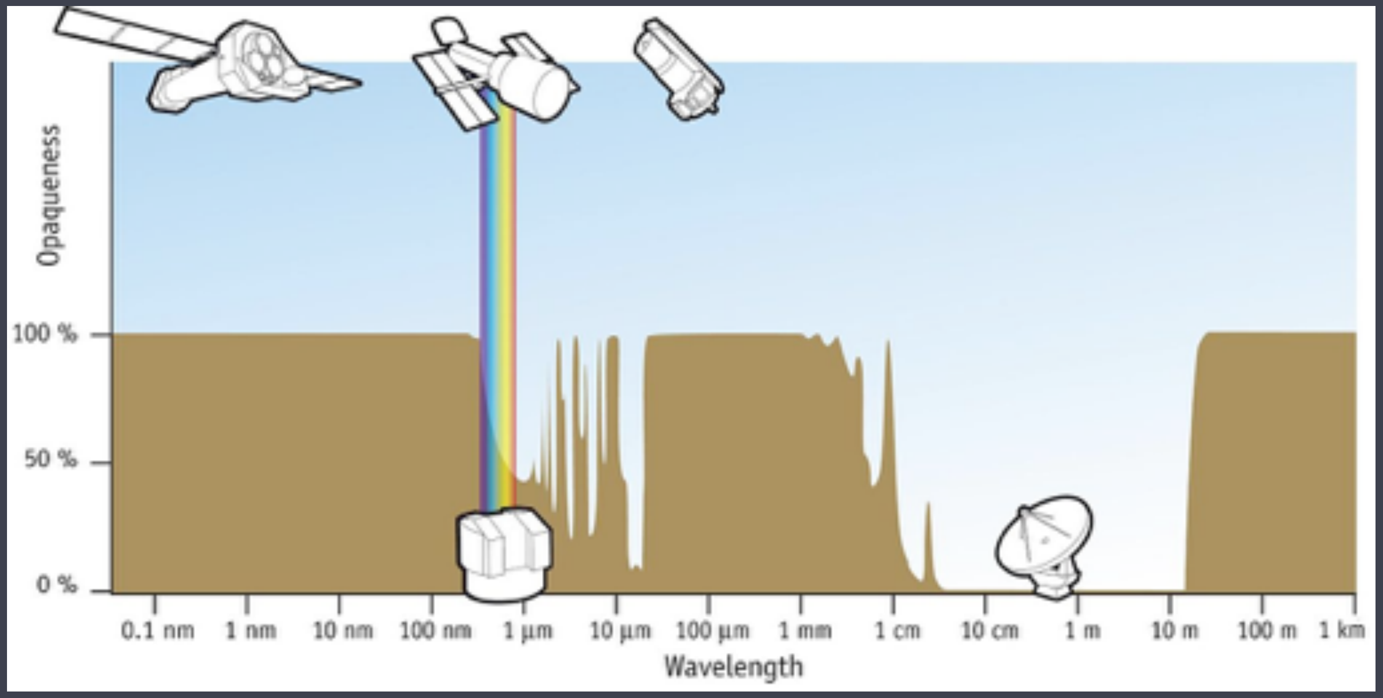
X-ray Astronomy was born in the 1960-70's

state of knowledge in the mid-70s:

Massive stars don't have convective surfaces

And they don't have magnetic fields (with a few notable exceptions)

Einstein X-ray Observatory launched 1978



F. Granato (ESA/Hubble) - ESA/Hubble

unexpected discovery of massive star X-ray emission in 1979

THE ASTROPHYSICAL JOURNAL, 234:L51–54, 1979 November 15

DISCOVERY OF AN X-RAY STAR ASSOCIATION IN VI CYGNI (CYG OB2)

F. R. HARNDEN, JR., G. BRANDUARDI, M. ELVIS,[1] P. GORENSTEIN, J. GRINDLAY, J. P. PYE,[1] R. ROSNER, K. TOPKA, AND G. S. VAIANA[2]
Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts
Received 1979 June 26; accepted 1979 July 26

ABSTRACT

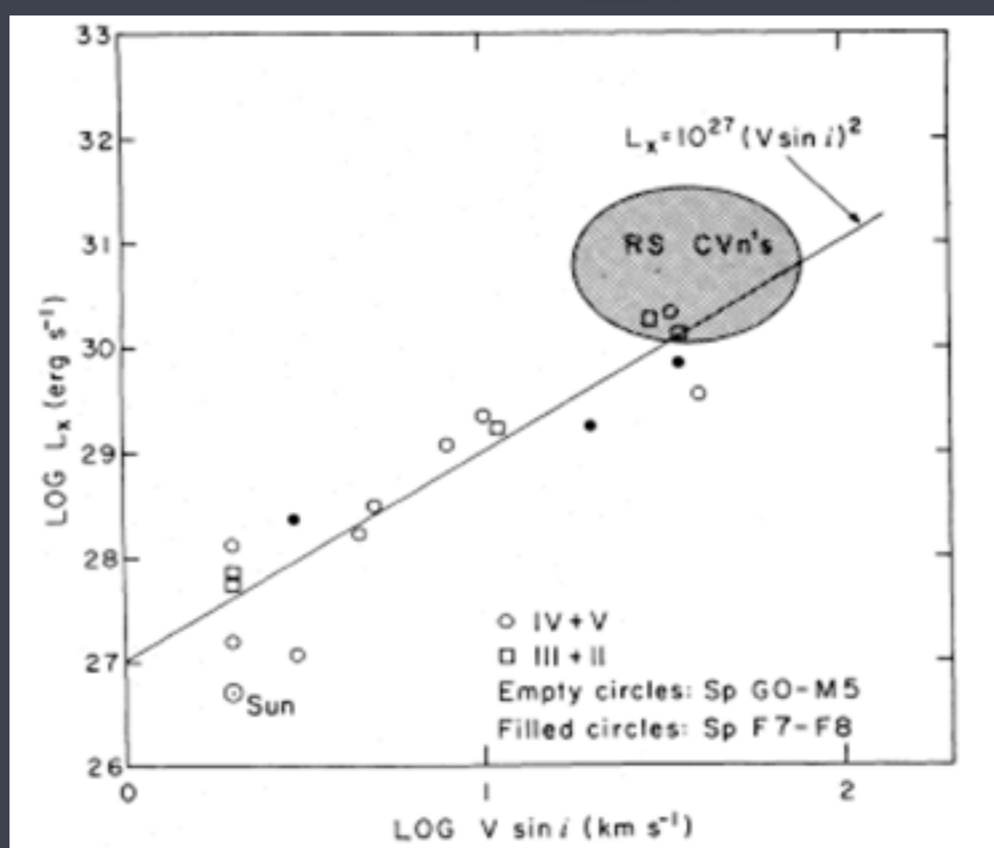
A group of six X-ray sources located within 0°4 of Cygnus X-3 has been discovered with the *Einstein* Observatory. These sources have been positively identified and five of them correspond to stars in the heavily obscured OB association VI Cygni. The optical counterparts include four of the most luminous O stars within the field of view and a B5 supergiant. These sources are found to have typical X-ray luminosities L_x (0.2–4.0 keV) $\sim 5 \times 10^{33}$ ergs s^{-1}, with temperatures $T \sim 10^{6.8}$ K and hydrogen column densities $N_H \sim 10^{22}$ cm^{-2}, and therefore comprise a new class of low-luminosity galactic X-ray sources associated with early-type stars.

Massive star X-ray emission is different from low-mass stellar X-ray emission

No observed correlation between rotation and X-rays for the massive stars

low mass

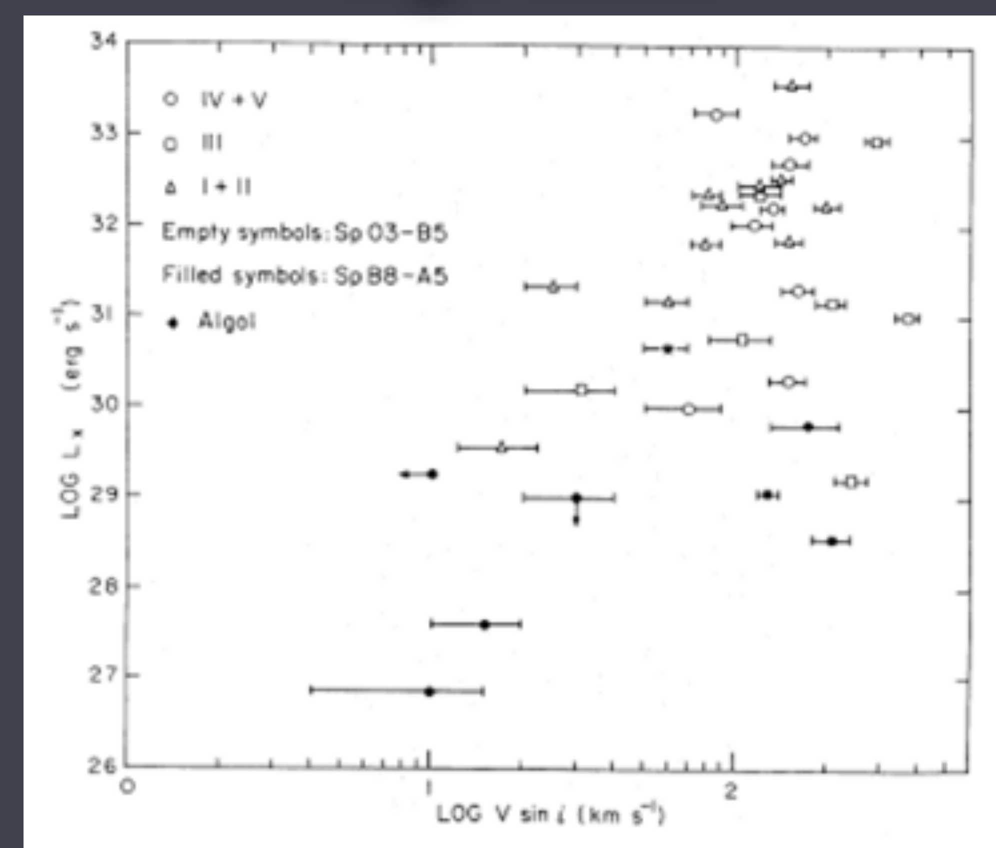
X-ray luminosity



rotation

high mass

X-ray luminosity



rotation

Chandra launched in 1999 - first high-resolution X-ray spectrograph

response to photons with $h\nu \sim 0.5$ keV up to a few keV (corresp. ~5Å to 24Å)

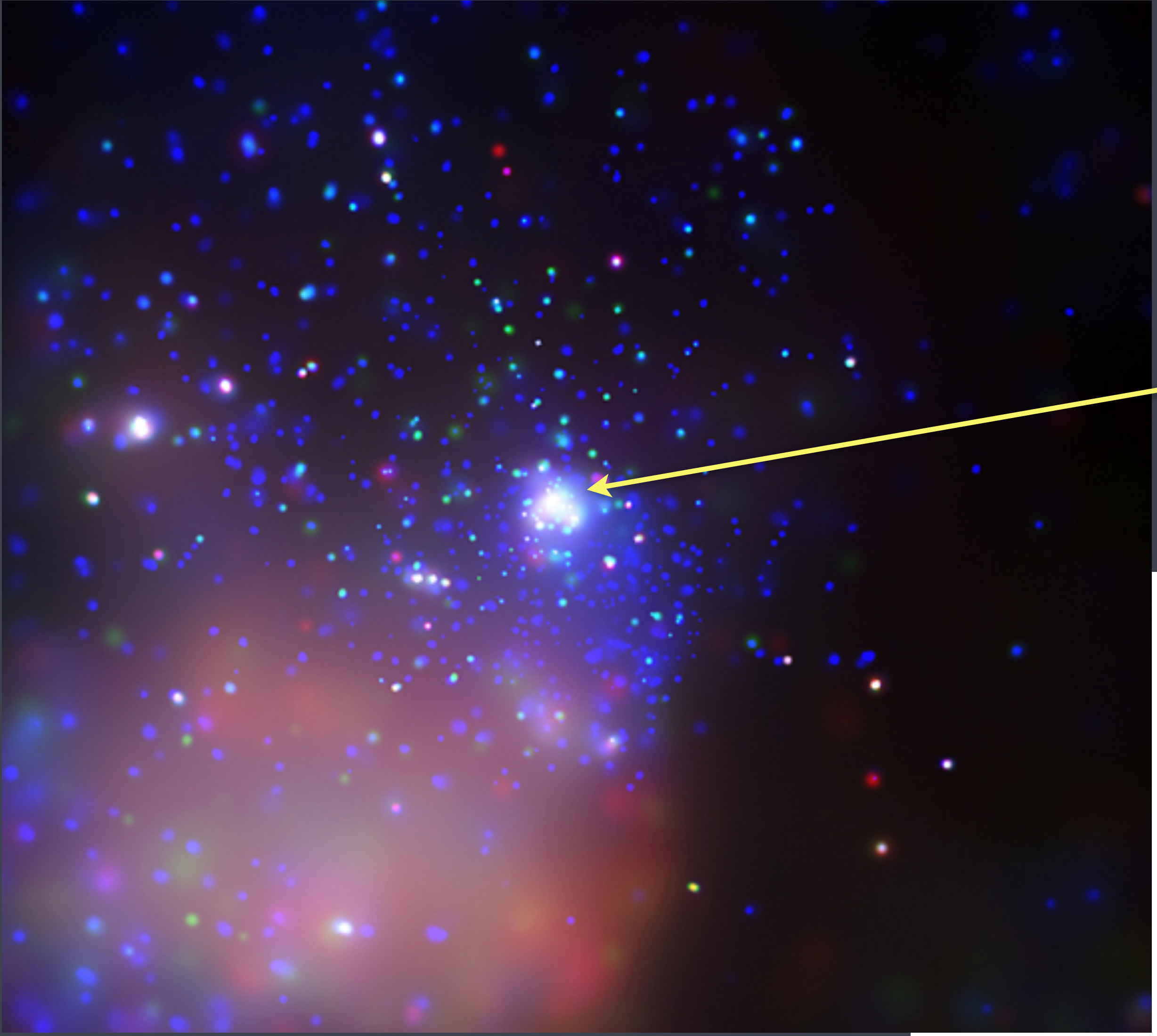
X-ray imaging? > 0.5 arc sec, at best (100s of AU)

spectroscopy ($\lambda/\Delta\lambda$ < 1000 corresp. v > 300 km/s)

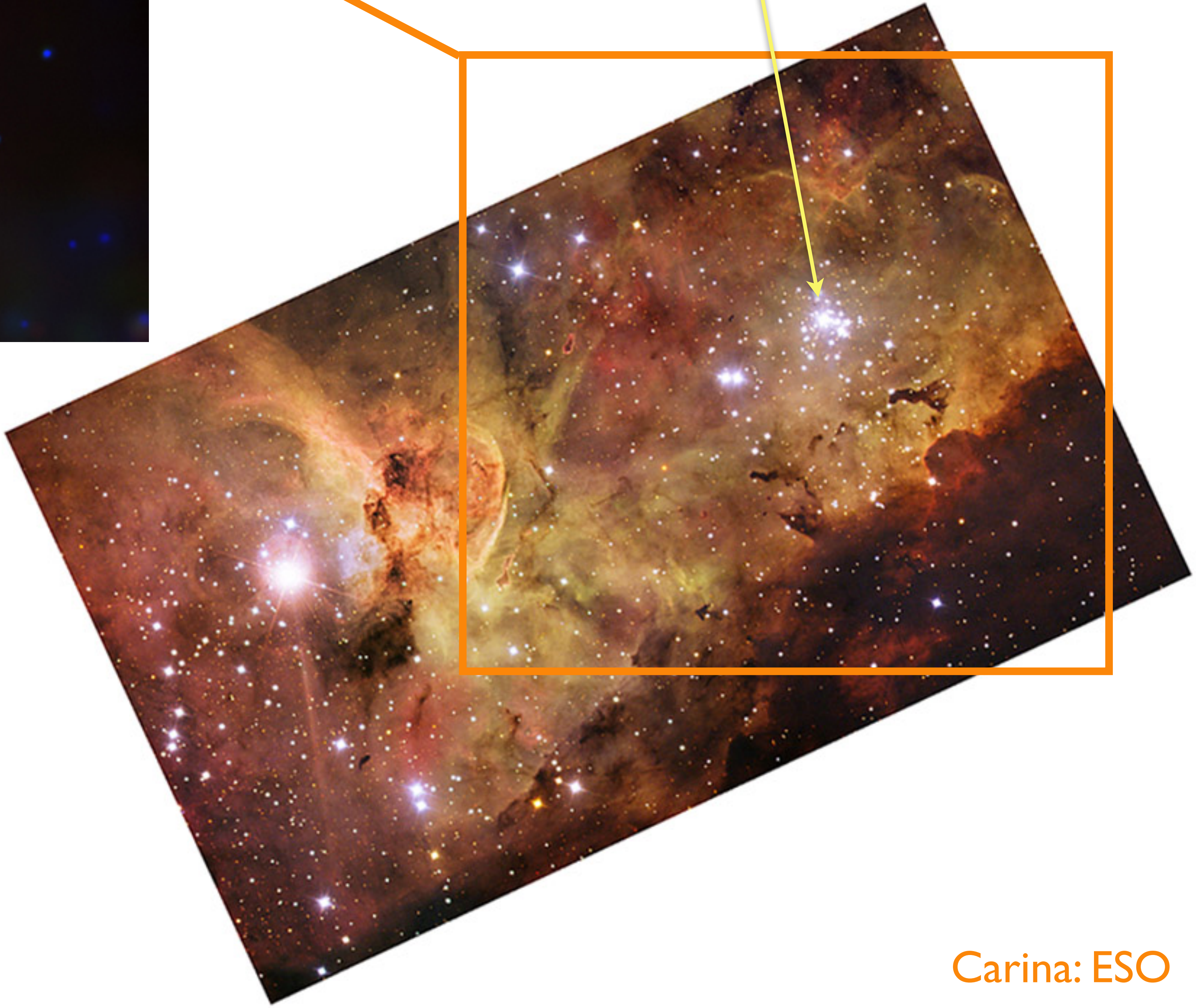
The Carina Complex

X-ray image to the left

HD 93129A (O2)



Tr 14 in Carina: *Chandra*



Carina: ESO

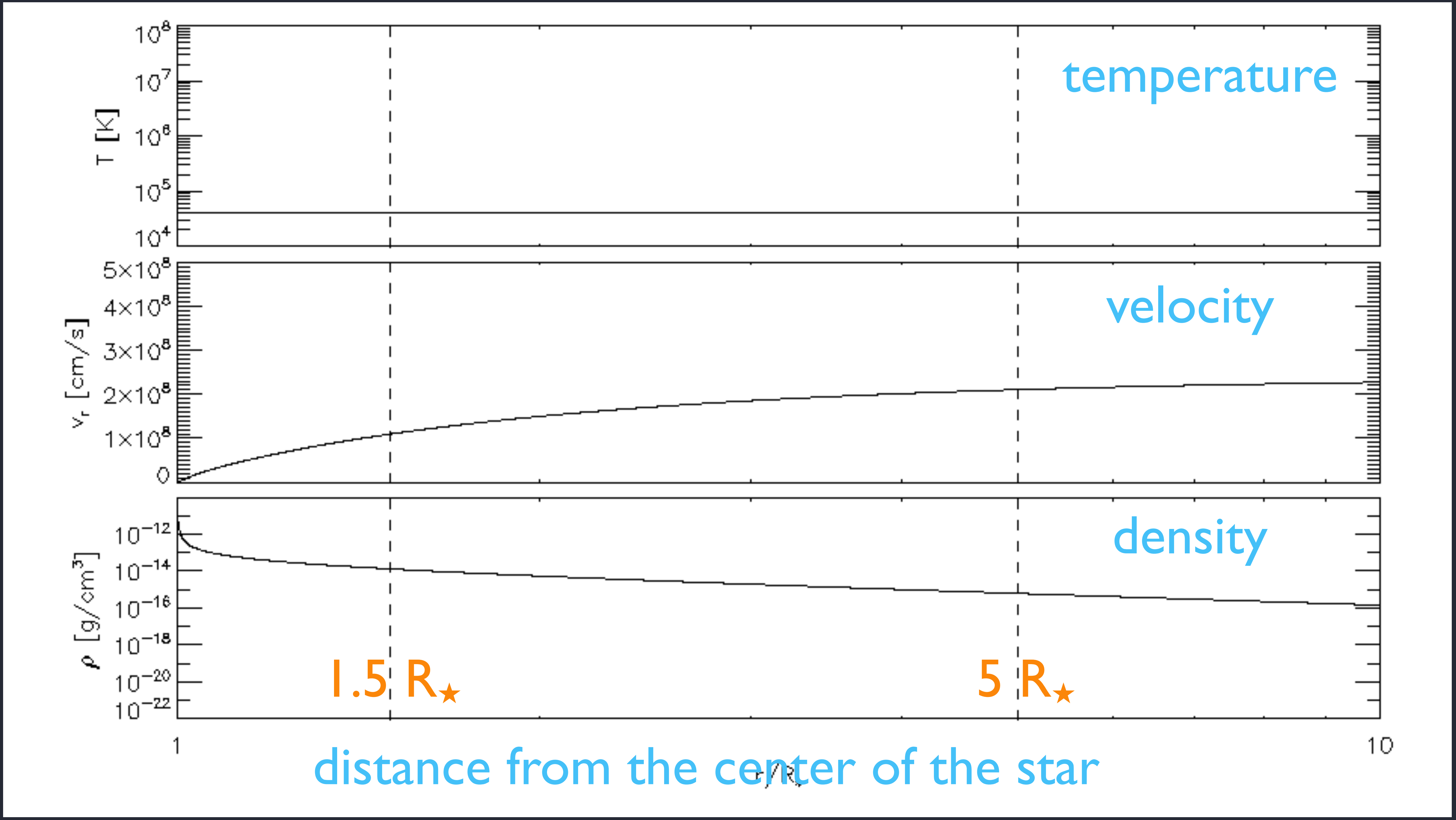
Shock Waves

http://apod.nasa.gov/apod/ap030504.html (John Gay)

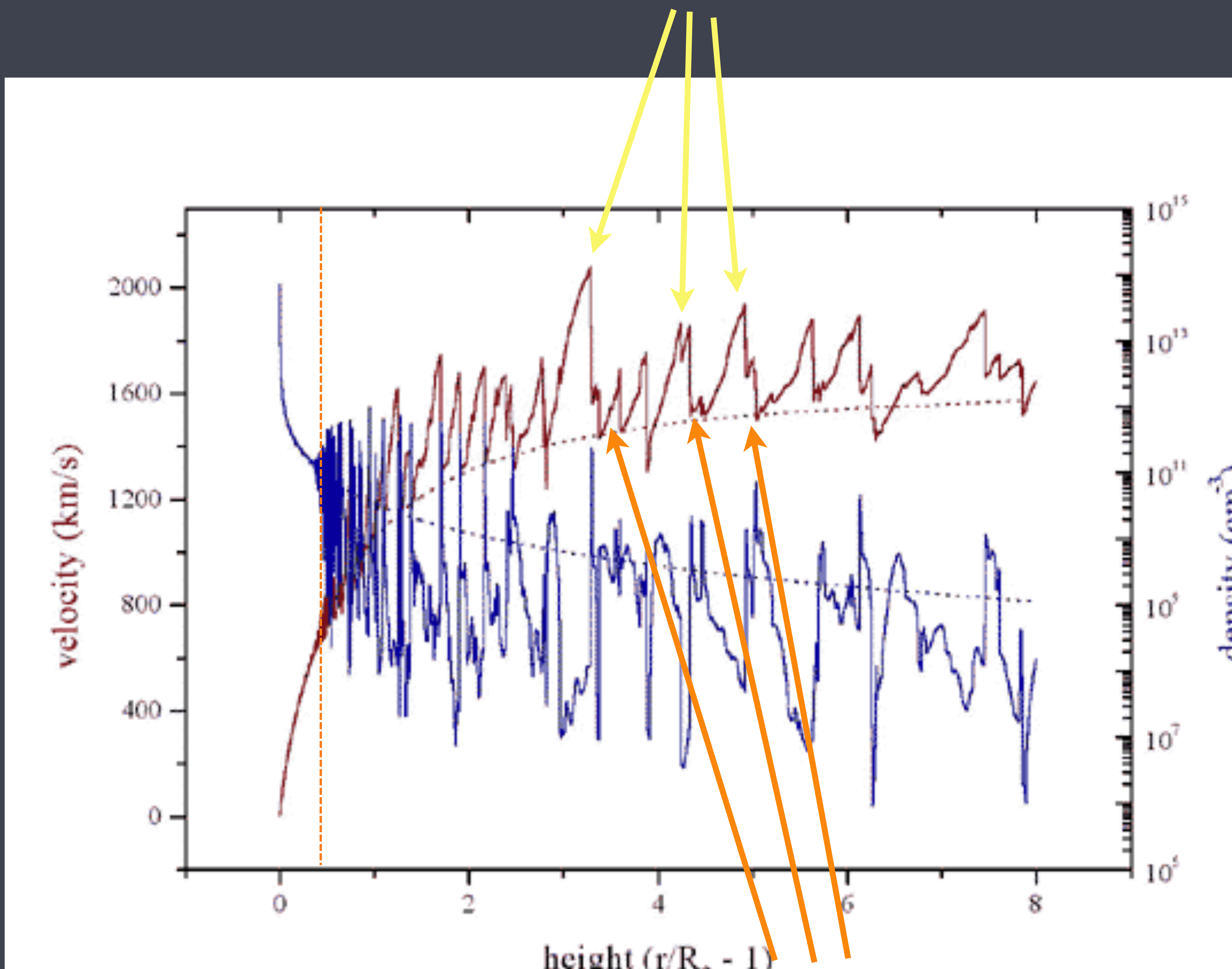
Numerical models of an O star wind

intrinsic instability of radiative driving, Line Deshadowing Instability (LDI), leads to shock-heating of the wind

movie available at: http://astro.swarthmore.edu/~cohen/projects/ldi/ifrc3_abbott0.65_xkovbc350._xmbko1.e-2_epsabs-1.e-20.gif



$V_{shock} \sim 300$ km/s : $T \sim 10^6$ K



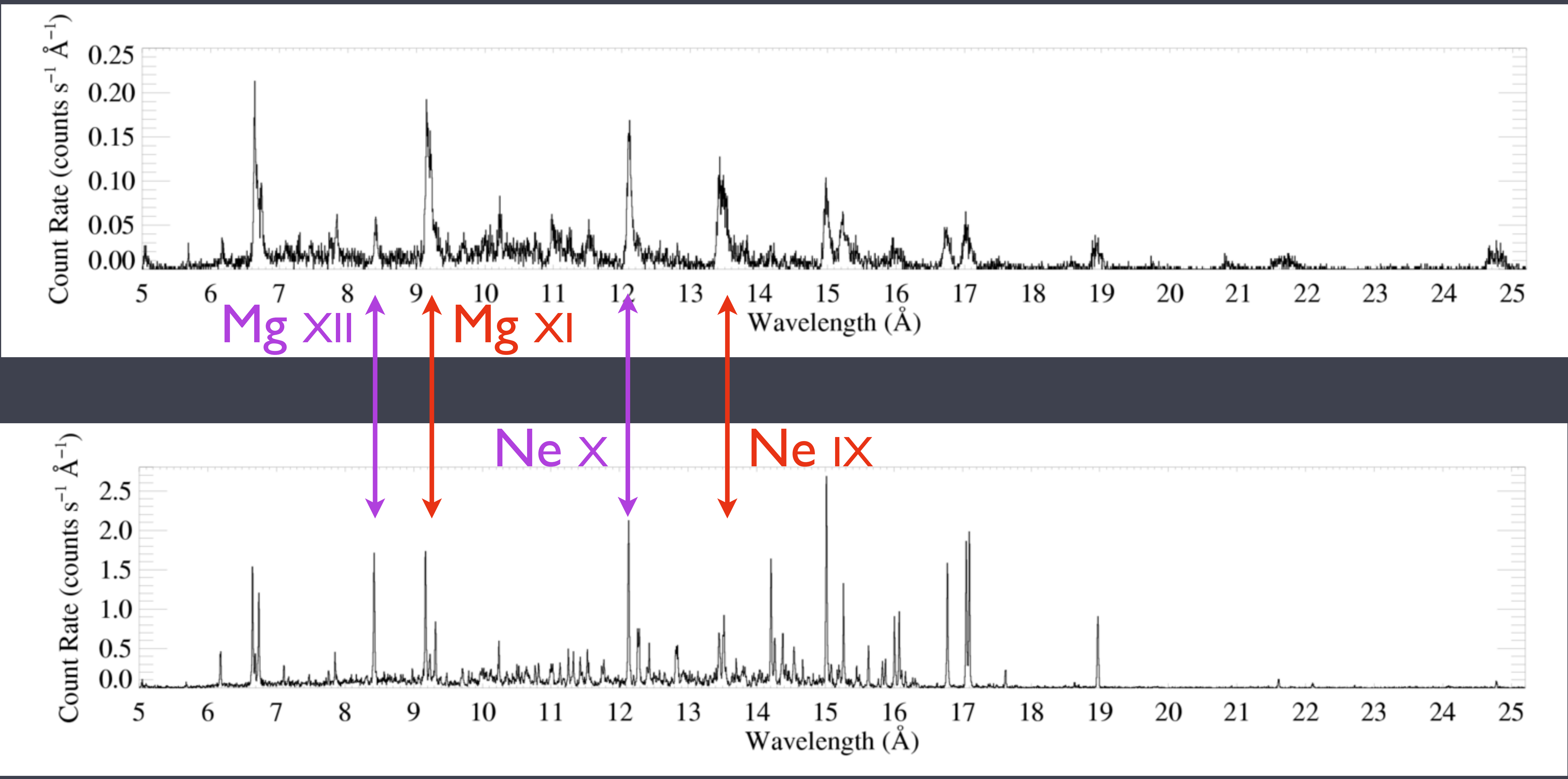
shocked wind plasma is decelerated back down to the local wind velocity

Chandra grating spectroscopy

ζ Pup (O4 If)

Chandra grating (HETGS/MEG) spectra

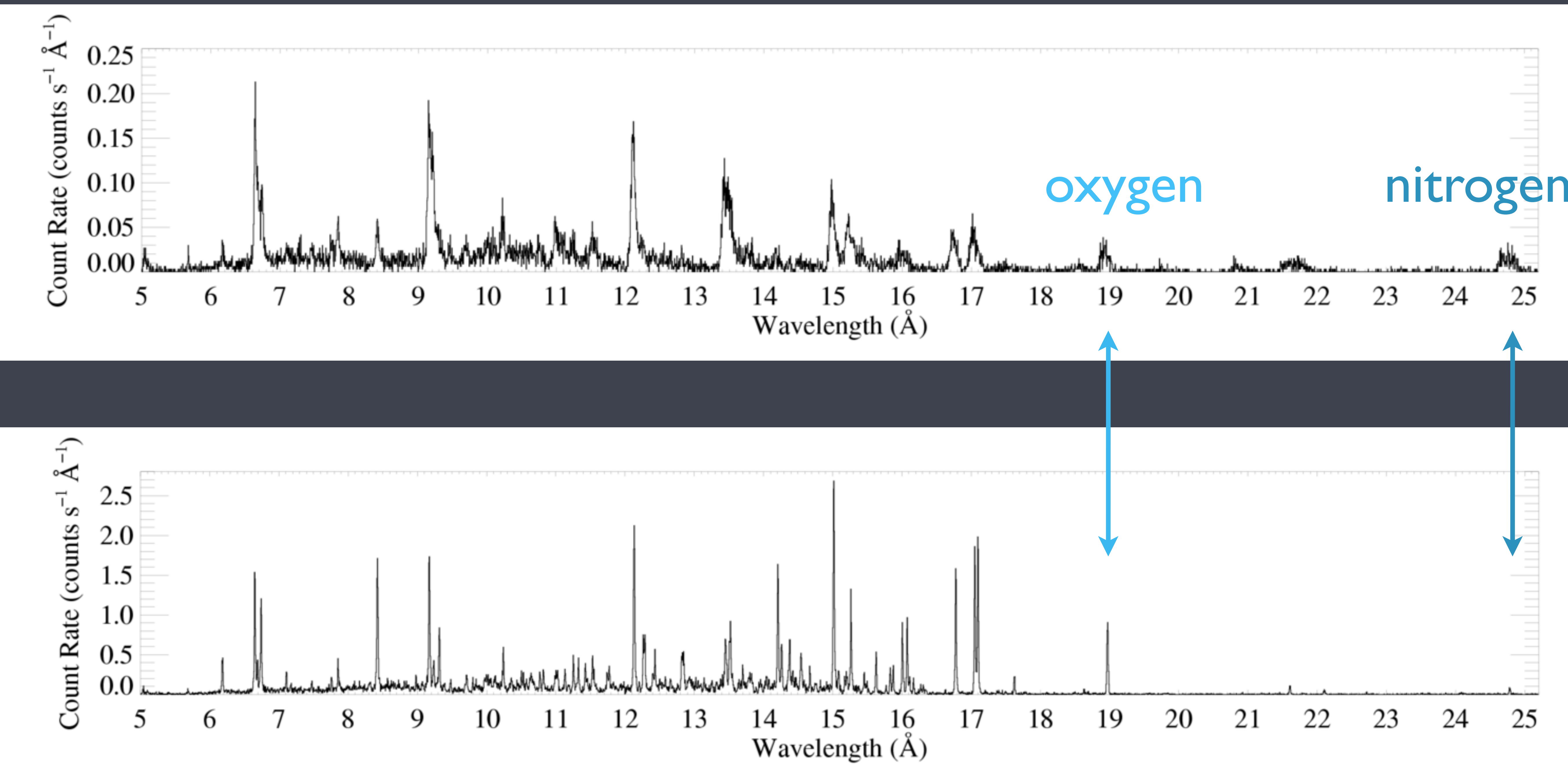
ζ Pup (O4 If)



Capella (G5 III)

elemental abundances can also be determined

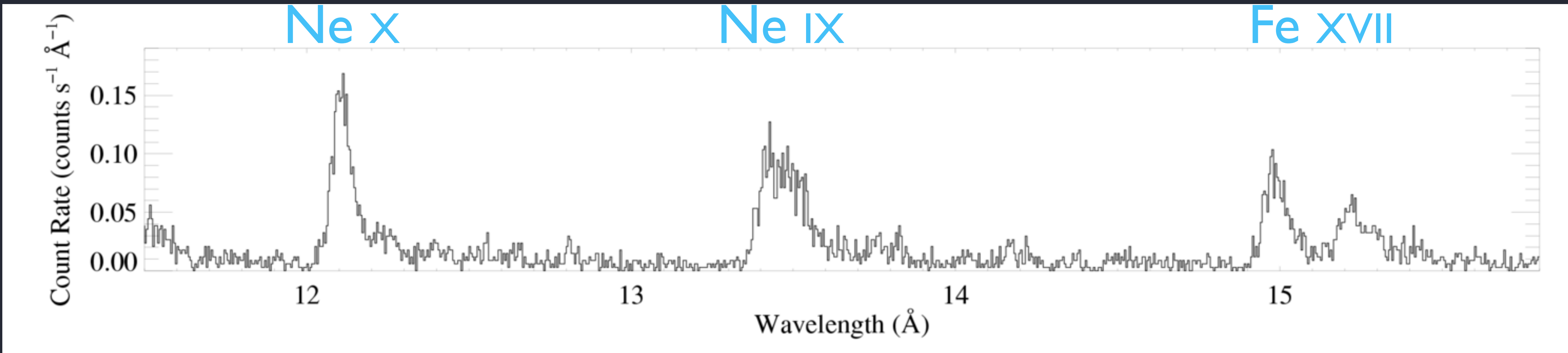
ζ Pup (O4 If)

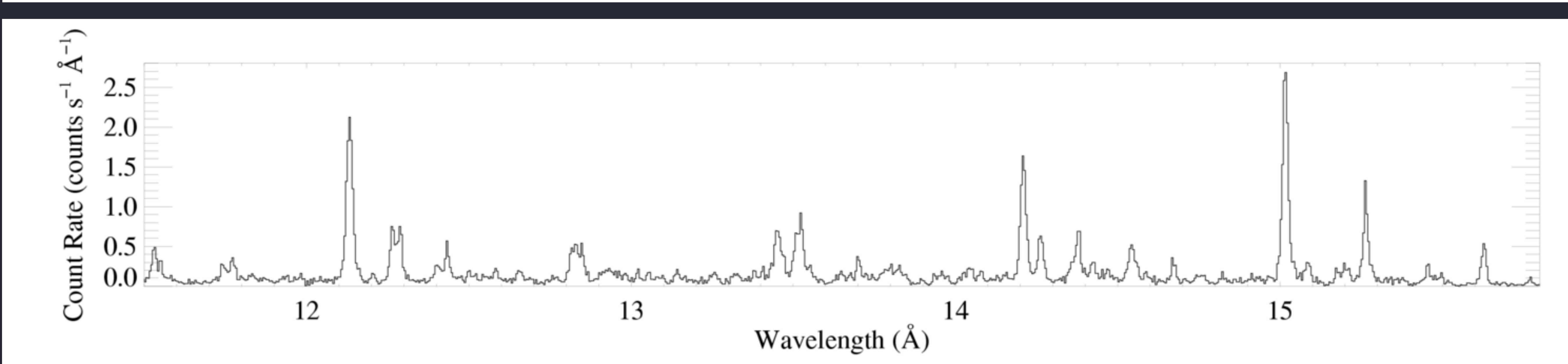


Capella (G5 III)

Zoom in

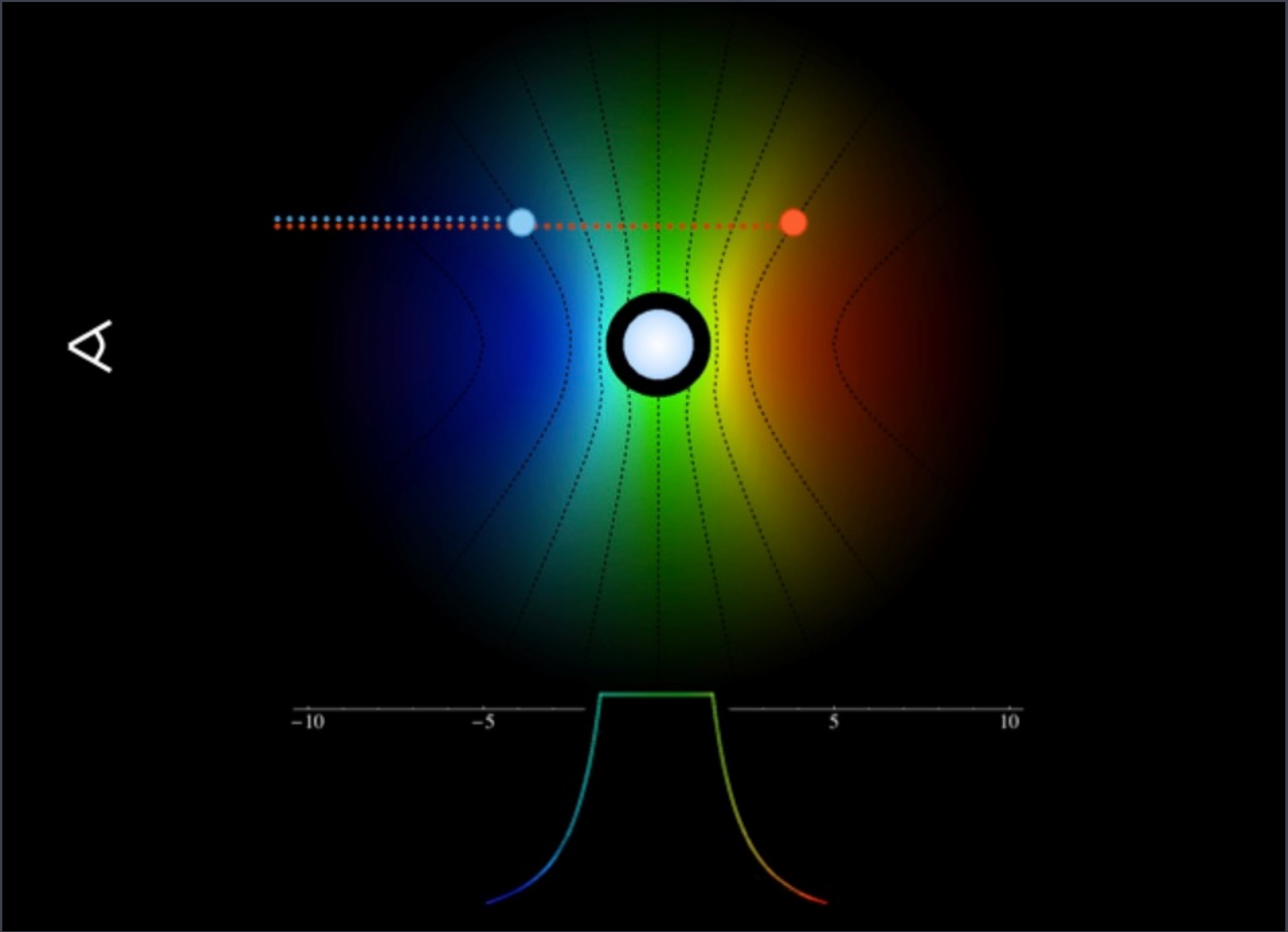
ζ Pup (O4 If)





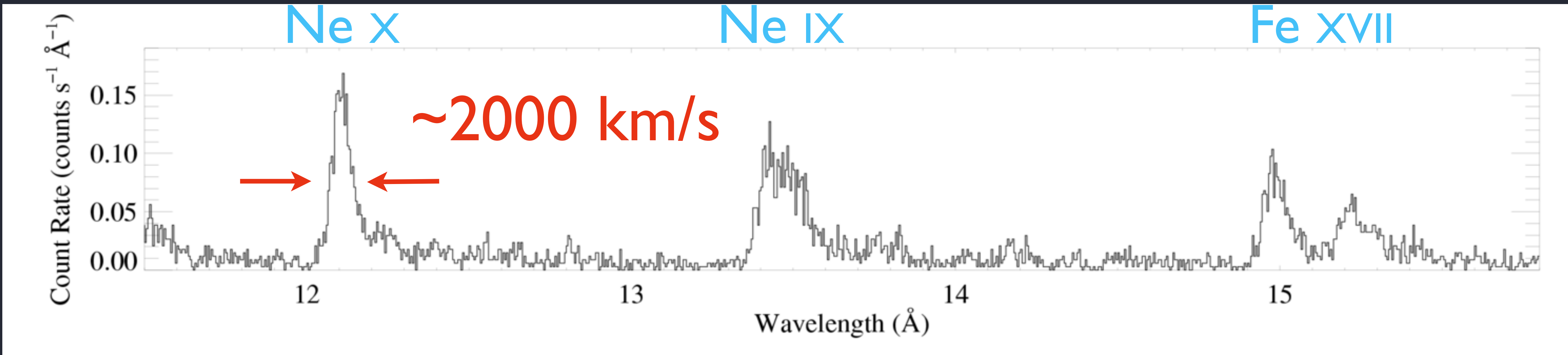
Capella (G5 III)

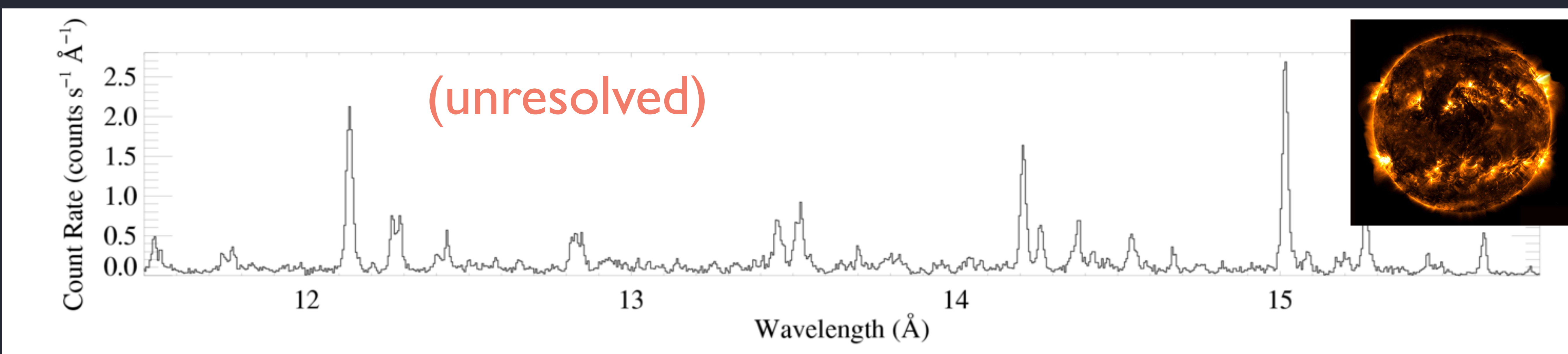
consider the Doppler shift



Zoom in

ζ Pup (O4 If)

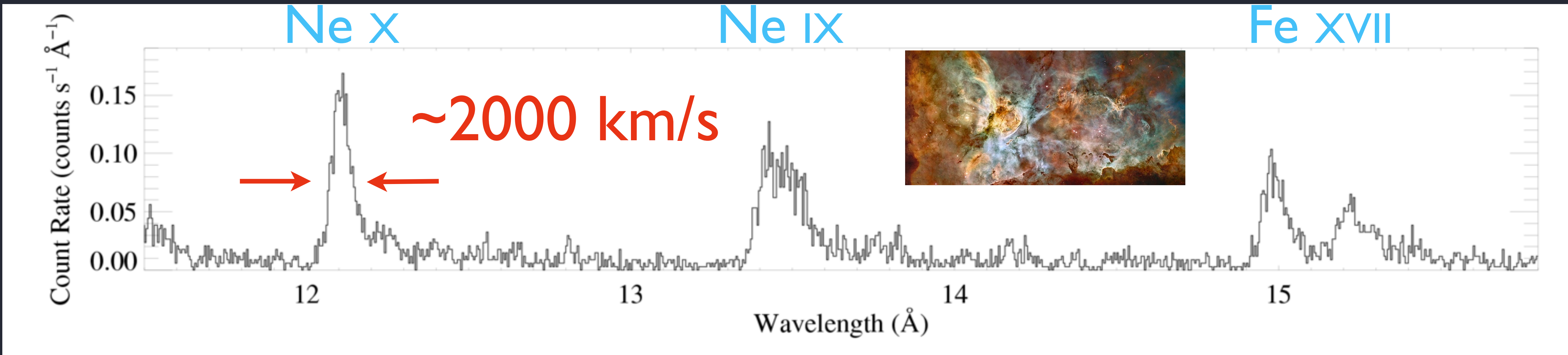


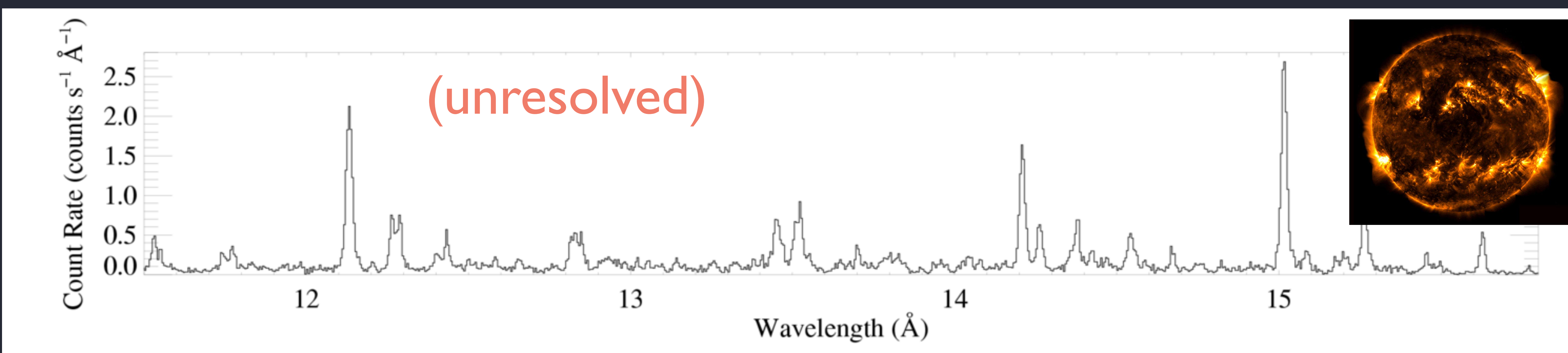


Capella (G5 III)

conclusive evidence that the X-ray plasma is in the stellar wind

ζ Pup (O4 If)





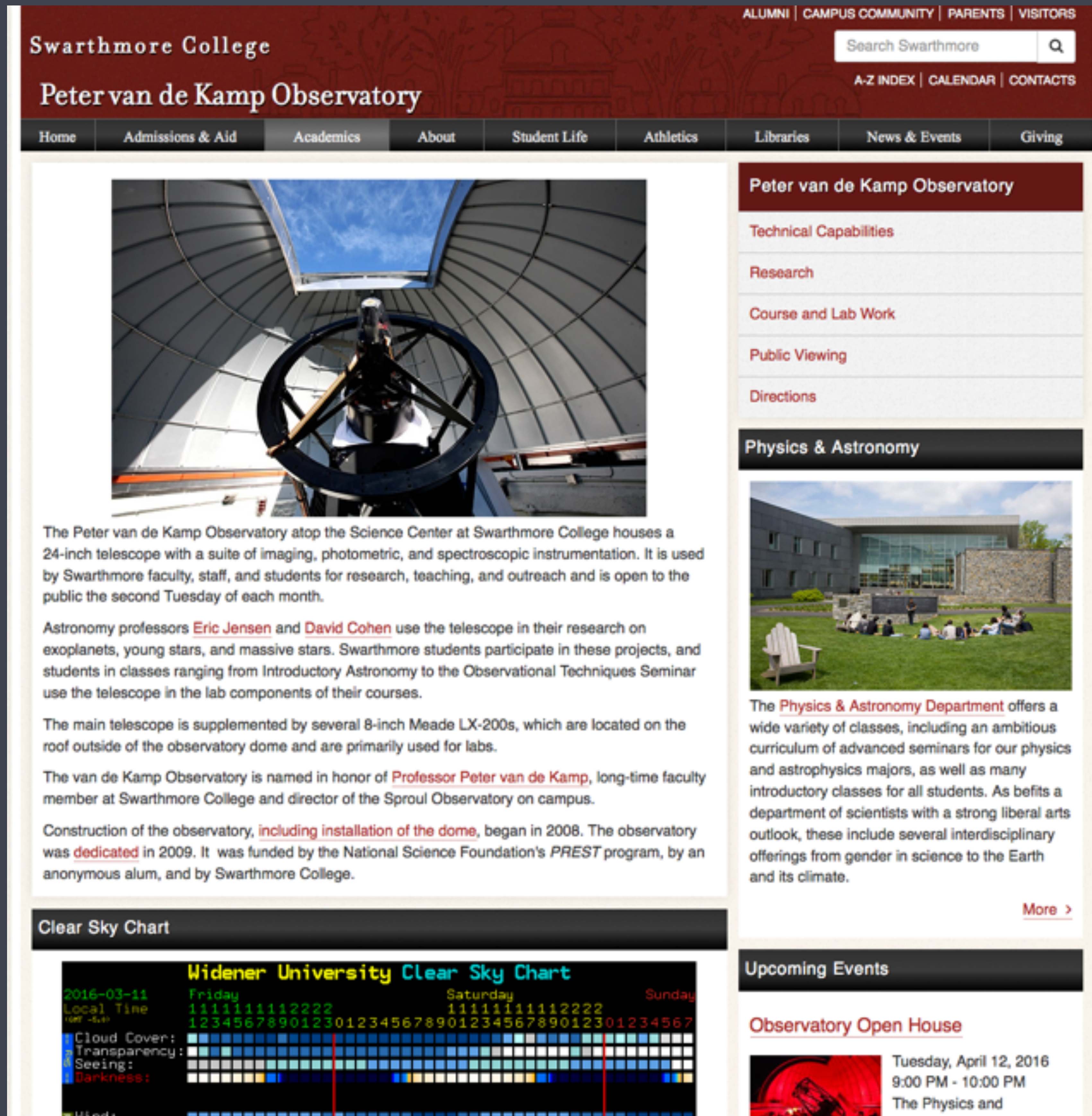
Capella (G5 III)

Conclusions

- Massive stars dominate the energetics of the Galaxy and produce heavy elements
- Their radiation-driven stellar winds cycle those elements back into the Galaxy
- And their winds are the source of their X-ray emission



Open House at the Peter van de Kamp Observatory - 2nd Tuesday of each month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Peter van de Kamp Observatory

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The Peter van de Kamp Observatory atop the Science Center at Swarthmore College houses a 24-inch telescope with a suite of imaging, photometric, and spectroscopic instrumentation. It is used by Swarthmore faculty, staff, and students for research, teaching, and outreach and is open to the public the second Tuesday of each month.

Astronomy professors Eric Jensen and David Cohen use the telescope in their research on exoplanets, young stars, and massive stars. Swarthmore students participate in these projects, and students in classes ranging from Introductory Astronomy to the Observational Techniques Seminar use the telescope in the lab components of their courses.

The main telescope is supplemented by several 8-inch Meade LX-200s, which are located on the roof outside of the observatory dome and are primarily used for labs.

The van de Kamp Observatory is named in honor of Professor Peter van de Kamp, long-time faculty member at Swarthmore College and director of the Sproul Observatory on campus.

Construction of the observatory, including installation of the dome, began in 2008. The observatory was dedicated in 2009. It was funded by the National Science Foundation's *PREST* program, by an anonymous alum, and by Swarthmore College.

Clear Sky Chart

Widener University Clear Sky Chart

2016-03-11

Local Time

Friday | Saturday | Sunday

Cloud Cover:

Transparency:

Seeing:

Darkness:

Wind:

Peter van de Kamp Observatory

- Technical Capabilities
- Research
- Course and Lab Work
- Public Viewing
- Directions

Physics & Astronomy

The Physics & Astronomy Department offers a wide variety of classes, including an ambitious curriculum of advanced seminars for our physics and astrophysics majors, as well as many introductory classes for all students. As befits a department of scientists with a strong liberal arts outlook, these include several interdisciplinary offerings from gender in science to the Earth and its climate.

More ›

Upcoming Events

Observatory Open House

Tuesday, April 12, 2016
9:00 PM - 10:00 PM
The Physics and
Astronomy department